U.S. DEPARTMENT OF COMMERCE
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PB-265 467

Estuarine Pollution Control and Assessment. Proceedings of a Conference Volume I, and II

Environmental Protection Agency, Washington, D C

Mar 77

EPA 440/1-77-007

PB 265 467

ESTUARINE POLLUTION CONTROL AND ASSESSMENT

Proceedings of a Conference

VOLUME I

March 1977

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SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA 440/1-77-007	2.	3. Recipient's Accession No. PB-265 467
4. Title and Subtitle: Estuarine Pollution Control and Assessment, Proceedings of a Conference, Vols. I, II,			5. Report Date: March 1977 6.
7. Author(s): Office of Water Planning and Standards, U.S. Environmental Protection Agency			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: Same as box 12			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address: Office of Water Planning and Standards, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460			13. Type of Report & Period Covered: Final 14. EPA 700/01

15. Supplementary Notes: Vol III is available only on Microfiche. A copy is available for inspection at EPA Regional office libraries and EPA associated labs libraries.

16. Abstracts

This report is designed to provide information that could be used to establish a national program for the prevention, reduction, and elimination of pollution in estuaries. The individual papers comprising the report address important estuarine problems by presenting state-of-the-art knowledge and experience in the field. Volumes I and II contain the conference papers and Volume III is a microfiche index of federally funded estuarine research projects.

17. Key Words and Document Analysis. 17a. Descriptors

Estuaries
Water resources
Water pollution
Biological productivity
Dredging
Industrial wastes
Indicator Species
Wildlife
Recreation
Sedimentation
Nutrients
Fisheries
Materials Recovery
Mathematical modeling
Monitoring

17b. Identifiers/Open-Ended Terms

Estuary management
Thermal discharges
Oil pollution
Solid Waste Disposal
Heavy metals
Economic factors
Land Use Controls
Regulations
Chemical contaminants
Wastewater management

17c. COSATI Field/Group 0810

18. Availability Statement: Release Unlimited	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 760
	20. Security Class (This Page) UNCLASSIFIED	22. Price PC A99 / MF A01

TIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

ESTUARINE POLLUTION CONTROL AND ASSESSMENT

Proceedings of a Conference

VOLUME I

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PLANNING AND STANDARDS
WASHINGTON, D.C.

The contents of this publication do not reflect official policies of either the Environmental Protection Agency or any other governmental unit. Statements contained herein are to be ascribed solely to their authors.

OVERVIEW

PREFACE

This report is designed to provide information that could be used to establish a national program for the prevention, reduction, and elimination of pollution in estuaries. The Environmental Protection Agency has attempted to identify important estuarine problems by soliciting written state-of-the-knowledge reports from leading scientists working in the field. During April 1974 EPA met with the governing board of the Estuarine Research Federation (ERF), a professional society of some 1,500 estuarine scientists. The purpose of this meeting was to request the Federation's participation in selecting the most knowledgeable contributors.

On May 30, 1974 an interagency ad hoc working group was established to refine the reporting effort approach and to establish the content and format of the report. The group included representatives of EPA, ERF, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration (NOAA), the Smithsonian Institution, and various academic institutions.

From a list of possible contributors, 57 were selected. Their efforts are included in the second part of this report. A set of guidelines, developed by the working group, was distributed to these authors requesting a presentation of approximately 20 pages in a style aimed at a layman audience. In selecting the authors, an attempt was made to provide a balanced representation from the academic, governmental, and industrial communities, including differing or opposing points of view.

Additionally, a letter requesting information was sent to the National Association of Manufacturers, with specific letters to 23 member industries in the Association. Further, those federal agencies with estuarine pollution control programs were formally asked to supply information for inclusion in the study. With all requests for information, guidance in preparation was provided. All materials received are either summarized or included *in toto* as the Individual Contributions section of this document.

Each contribution was examined by a minimum of two outside reviewers selected by the Estuarine Research Federation. Authors were provided with the reviewers' comments and encouraged to revise their manuscripts accordingly; however, revisions were not mandatory. Participating reviewers are listed in Appendix A.

Each contributor was invited to present a summary of his paper during a symposium at Pensacola, Fla., from February 11 to 13, 1975. Numerous government representatives were invited to attend. A complete list of attendees appears in Appendix B.

The meeting was organized to allow as much time as possible for discussion. The intent was to provide contributors with additional information for inclusion in the final version of their papers, and more importantly, to provide the convenors with a basis for preparation of a useful overview report. The symposium was divided into the following sessions:

Research Applications
Estuarine Systems
Other Pollutants
Dredging Effects
Nutrients
Fisheries
Ports
Industry
Power Plant Effects
Public's Role
Legal Aspects
Living and Non-Living Resources
Economics
Concluding Remarks.

In order to capture the essence of the conference, summaries of these sessions were prepared and appear in this report. A committee was chosen from the participants to develop the conference format and prepare the summaries. This committee included:

Dr. Robert Biggs, Assistant Dean, College of Marine Studies, University of Delaware

Dr. David Correll, Rhode River Program, Smithsonian Institution

Dr. John Costlow, Director, Duke University Marine Laboratory

Dr. L. Eugene Cronin, Associate Director for the Research Center for Environmental & Estuarine Studies, University of Maryland

Dr. William P. Davis, Chief, Bears Bluff Field Station, U. S. Environmental Protection Agency

Dr. David Flemer, Office of Biological Services, U. S. Fish and Wildlife Service

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Dr. M. Grant Gross, Director, Chesapeake Bay Institute, the Johns Hopkins University

Dr. Thomas Hopkins, Chairman, Department of Biology, University of West Florida

Mr. Kent Hughes, Special Assistant for Marine Science Environmental Data Service, National Oceanic & Atmospheric Administration

Mr. Robert Johnson, Office of Water Planning & Standards, U. S. Environmental Protection Agency

Mr. Edward Langlois, President, Portland Harbor Pollution Abatement Committee, Portland, Maine

Dr. J. L. McHugh, Marine Sciences Research Center, State University of New York at Stony Brook

Dr. Joseph Mihursky, Chesapeake Biological Laboratory, University of Maryland

Mr. Thomas Pheiffer, Annapolis Field Station, U. S. Environmental Protection Agency

Dr. William Queen, Department of Biology, Maryland University

Mr. Kenneth Roberts, Resource Research Specialist, Office of Living Resources, National Oceanic & Atmospheric Administration

Dr. J. R. Schubel, Director, Marine Sciences Research Center, State University of New York at Stony Brook

Dr. Albert Sherk, Office of Biological Services, U. S. Fish & Wildlife Service

Prof. Jerome Williams, Associate Chairman, Department of Environmental Sciences, U. S. Naval Academy

It is important to recognise that only a few of the individual authors had the opportunity to contribute to or review the session summaries. It is hoped, however, that all points of view have been accurately presented by the Committee.

To more effectively popularize some of the concepts expressed in this report, a 28-minute motion picture entitled "Estuary" has been prepared as a joint production of NOAA and EPA. The film illustrates aspects of estuarine pollution, associated problems, and conflicts. It also attempts to describe some approaches that have been, or could be utilized in addressing these problems. The film may be ordered from the NOAA Motion Picture Service, Rockville, Md.

A compilation of all federally funded estuarine research projects is included in the index, prepared by the Technical Information Unit of EPA's National Field Investigations Center in Denver, Colo. The index, on microfiche, is presented as the third volume of this report. The size of the index necessitated this form of presentation to conserve space, paper, and printing costs.

Special appreciation is extended to Dr. Thomas Duke and his staff at the EPA Gulf Breeze Laboratory, Pensacola, Fla., for their assistance in conducting the symposium. Their efforts have contributed significantly to the success of the entire project.

INTRODUCTION

Estuarine systems often are politically, economically, and ecologically complex, and major problems cannot be solved by piecemeal action. Research, planning and management of estuaries should be strongly oriented toward the entire system, with adequate consideration of the total watershed including land use and development as well as future trends.

Estuarine resources are demanded for many alternative uses such as waste assimilation, recreation and esthetic enjoyment. Some uses complement each other, many do not. In order to choose among competitive uses of estuarine resources, the benefits and the costs to society as a whole which arise from alternative uses must be systematically evaluated.

SYMPOSIUM ISSUES

A number of issues discussed at the EPA symposium stand out as being particularly important in terms of effective estuarine management. These issues are discussed in the summaries to follow and are more thoroughly examined in the individual papers included in the second part of this report. The three issues presented below are singled out because a number of the conference participants were motivated to discuss them at length in their written and oral presentations.

DATA SYSTEMS

In few estuaries are the data sufficient to establish historical trends in water quality. In no estuary is our knowledge of the prevailing processes adequate to unequivocally assess the causes of any persistent changes that may have occurred or may be occurring. Therefore, monitoring programs are important and must be continued, but they should be carefully designed to provide data that will also be useful in process-related studies. In light of our present inability to make quick assessments of existing estuarine environmental quality and changes occurring in coastal areas, our present national data storage and analysis systems must be re-evaluated. Additionally, it has become apparent that the utility of national data repositories is questionable when large numbers of users with many different needs are considered. Multiple regional data centers are much more flexible than a single system and therefore should be considered. The smaller size of regional centers would increase availability of regional data, increase the efficiency of the computer systems, and decrease maintenance costs. On the other hand, increasing the number of computer centers necessarily increases the work force, duplication of effort, and probably operating costs.

UTILIZATION OF ESTUARINE RESOURCES

Utilization of estuarine resources was a concern often expressed by the conference participants and attendees. Generally, two areas of concern were evident: (1) consumptive utilization of estuarine waters and (2) discharges of nutrients, thermal loadings, and fresh water to estuaries.

Consumptive utilization of estuarine waters is a necessary support function for numerous industrial processes, and vast quantities are also required for municipal and public use. Adequate water quality must be maintained if this consumptive utilization is to continue.

However, concern was expressed regarding the concept of uniform discharge controls for all estuaries. A suggested alternative to this approach is to base effluent discharge controls on assimilative capacity of the individual estuary. The assimilative capacity must be adequately defined in terms of the total flux of the estuary and the natural background levels of the pollutant being discharged. The objective should be to achieve the optimum use of each estuarine system commensurate with the manner in which the system naturally functions.

DREDGING AND SPOIL DISPOSAL

Although estuaries are natural areas of rapid sedimentation, man has dramatically increased the sediment influx to many of them. Sediment inputs associated with agricultural and construction efforts increase the need for maintenance dredging and therefore should be controlled at the source.

Because of the many different types of dredging and disposal techniques, the different types of dredged material involved, and the great diversity of estuarine environments, present chemical indices for classifying dredged material must be expanded from simple numerical values for adequate nationwide application.

RESEARCH NEEDS

Particular research areas considered by the contributors to require increased emphasis:

1. *Estuarine Models*—A review of estuarine modeling programs, both mathematical and hydraulic, identifying both their limitations and the circumstances in which they can be most profitably utilized, is necessary. Greater emphasis should be placed on the formulation of conceptual models and on attaining a better understanding of the processes that characterize the estuarine environment.

2. *Identification of Toxic Materials*—An increased effort is needed to identify the toxic substances introduced into the estuarine environment as a result of man's activities. An assessment of acute and chronic effects of these substances and their behavior in the estuarine environment is required.

3. *Natural Abundance Variations*—The effects of pollution on estuarine living resources cannot be determined unless natural abundance changes are known. An accelerated effort to make these determinations is therefore required.

4. *Microbial Populations*—Research should be supported to develop rapid techniques for detection of pathogens and for identification of more descriptive microbial indicator organisms.

5. *Natural Filters and Non-Point Sources*—The effect of natural ecological filters such as marsh areas on estuarine processes is not well understood. The possibility of practical application of this process in waste treatment, especially with regard to non-point sources, should be more fully investigated.

6. *Population Distribution Planning*—A critical assessment should be made of the need to recommend new types of controls required for population density in estuarine areas through appropriate zoning and land use management. Zoning and land use planning may not be adequate to control population pressures in estuarine areas.

SESSION SUMMARIES

ESTUARINE SYSTEMS

Each estuary is unique and is a complete, complex and unusually dynamic system, influenced by geographic location and seasonal variations. While much useful knowledge has been gained from research on the individual parts of estuaries and on the separate processes which occur, some of the most serious past failures in effective estuarine management have been caused by attempting to deal with problems as isolated events. Rather, the total estuarine system must be considered.

Recent research has made substantial contributions to our ability to analyze estuarine systems, and important progress is being made at several study sites. Despite the diversity of estuaries, a study of principal types, supplemented by local investigations to identify special problems can aid management of all estuarine systems.

Both estuarine management and estuarine system research are hampered frequently by the political, economic, and ecological complexity of the estuary. Piecemeal approaches are not as useful as a total approach, but cooperative attitude between governments and business can produce beneficial estuarine management programs. Increased research on estuaries as systems will prove to be of exceptional practical value in our efforts to achieve a balance among the ever-increasing uses.

LIVING AND NON-LIVING RESOURCES

Serious public concern exists regarding the fate of the nation's estuaries, and their attendant resources. During the period 1965–1975, legislative and administrative bodies in coastal states acted to protect living and non-living resources of estuaries by banning indiscriminate destruction of estuarine marshes; by considering fish and wildlife values equally with economic, social and legal issues in Federal decisions affecting estuaries; and by recognizing living and non-living resource values in coastal zone planning.

Even though governmental authority to consider living and natural resources of estuaries has been strengthened, problems remain. As yet minimal consideration has been given to aesthetic values when the potential impact of proposed actions within estuarine systems are evaluated. These aesthetic qualities of the shore zone (mixtures of land and seascapes) are as important in attracting people to the coastal estuaries as marine fish and shellfish, waterfowl, and marsh furbearers. Potential aesthetic impacts must be considered as well as biological, water quality and economic impacts. The conference participants recommend that regulatory agencies further develop criteria and guidelines to be used in aesthetic assessments and institute research projects designed to provide information essential to these criteria (see Fig. 1).

Environmental protection policies and programs are, for the most part, designed to prevent or minimize further environmental degradation. Unfortunately, many estuarine areas became degraded before these policies and programs were implemented. Recently, efforts have been made to rehabilitate some derelict areas. The participants suggest that these rehabilitation efforts be continued and extended when possible, along with associated research on habitat rehabilitation.

FISHERIES

Estuaries are an important part of the fishery resource of the United States. Estuarine environments generally are biologically more highly productive per unit area than the open sea. About two-thirds of the commercial and recreational fish and shellfish of the United States spend important parts of their lives, or their entire lives, in estuaries. Thus, management of these resources depends in large degree on maintenance of the quality of the estuarine environment.

Despite the acknowledged importance of estuaries to the fisheries of the nation, the effects of estuarine pollution on the living resources are not well understood. One complicating factor is that, although the estuarine environment is rich biologically, it is also a highly variable environment—a harsh environment at times. This variability produces wide fluctuations in abundance of estuarine resources brought about by natural causes, and these variations usually are impossible to distinguish from those caused by human activities such as engineering works and fishing, as well as water pollution. As an example, Fig. 2 illustrates fluctuations in the abundance of starfish in Long Island Sound for the years 1937 to 1961.

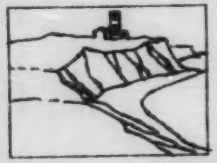
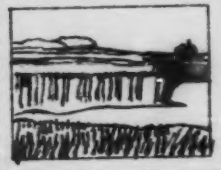
	Resource Type	(Selected) Visual Attribute(s)	(Selected) Intangible Attribute(s)	Managerial Implications	Institutional Implications
	beach	-sand qualities -forms -sweep	-molding by sea energy -primordial state, geological record	-exclusion or regulation of structures -debris, trash, dune buggy regulation -user-capacity determinations	-town exclusionary use vs. open public use (visual access) -public use of private beaches -maintenance funding
	riverbank	-landform configuration -vegetative characteristics -space/closure patterns	-order given to rural and urban land use -natural corridor provides physchological linkage to both source region and sea	-bank erosion protection -vegetative edge protection -clearance and planting management -urban area rehabilitation	-conciliation of split jurisdictions over riverbank areas -administration of public access and access acquisition
	bluff	-landform face -crest patterns -height	-impressiveness -sense of geological process -sense of hazard	-exclusion or regulation of use on or near crest and face -cautionary use of erosion protection measures	-development of legislative and administrative regulation of bluff areas
	tidal marsh	-vegetative infrastructures -seasonal change -wind imprints -tidal changes	-sense of (urban) endangerment -sense of significance in estuarine ecosystem	-prohibition of dredging, filling -regulation of permitted, compatible use	-development of legislative and administrative regulation of marsh areas

FIGURE 1.—Selected aesthetic resource and problem definitions.

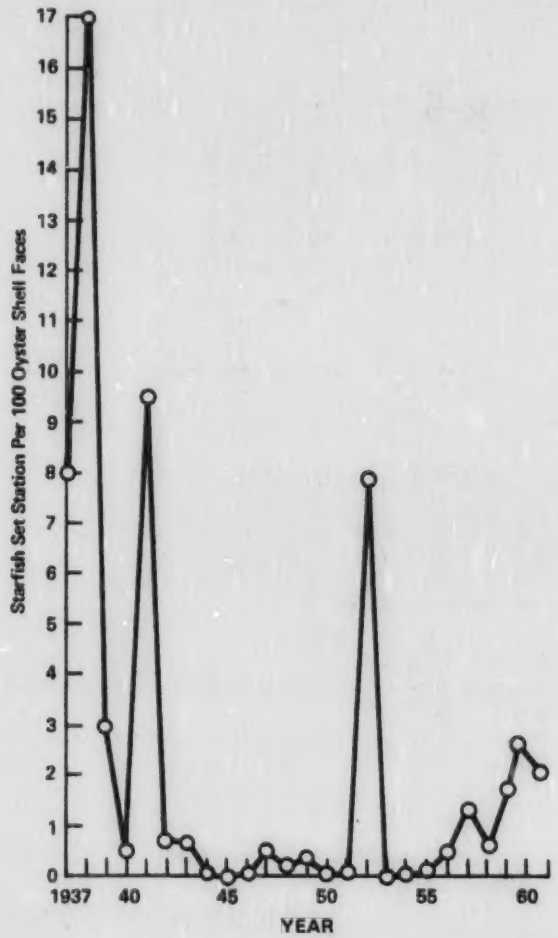


FIGURE 2.—Variations in Long Island Sound sea star abundance, 1937–61.

At the same time, the marked variability of this highly productive environment illustrates the resilience of living resources and underscores their ability to recover from catastrophic events occurring naturally or of human origin. Only by examining sessile resources like oysters and clams can we assess the adverse effects of environmental degradation. Existing knowledge must be fully utilized in this assessment and supplemented with estimates of standing crop, commercial and recreational catches, renewal rates, and natural mortality for most of these resources.

Despite the lack of data concerning the effects of estuarine pollution upon living marine resources of commercial and recreational value, the net effects of water pollution can be presumed to be adverse. Undeniable direct proof probably will never be available. Results of experimental studies indicate that every possible effort must be made to control and, where possible, to mitigate estuarine water pollution.

DREDGING EFFECTS

Although estuaries are areas of naturally rapid sedimentation, man has dramatically increased the sediment influx to many estuaries through his activities, not only within the estuarine zone, but throughout the estuarine drainage basins. Increased sediment inputs largely reflect increased erosion rates resulting from poor soil conservation practices associated with agricultural, strip mining, and construction activities. Local production of biologically produced sediment within the estuary has been stimulated by discharges of nutrient-rich waste water and runoff from agricultural and urban areas. Coupled with this ever increasing sediment input is the continuing requirement for deeper harbors to accommodate the newer, larger ships. The net effect has been a continual increase in dredging activity and cost as shown by Figure 3.

While construction of reservoirs and other engineering works occasionally has decreased the sediment inputs to some estuaries, the net effect has definitely been an increase in sediment loads. Significant progress has been made in controlling soil erosion in agricultural activities. Similar efforts

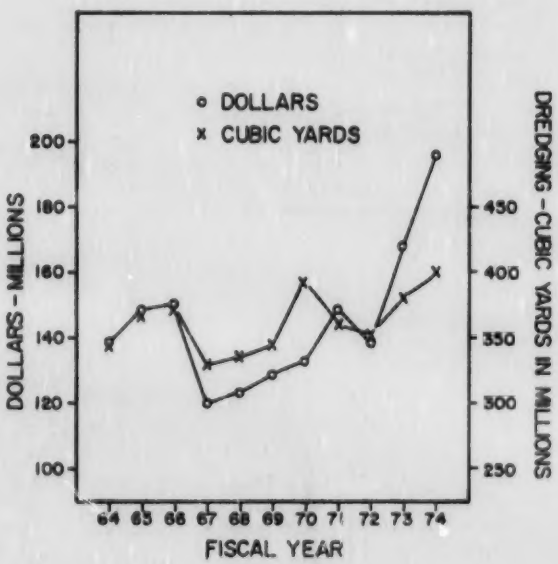


FIGURE 3.

in other areas must be intensified so that sedimentation may be reduced significantly within two decades. Until the influx of sediments can be curbed, maintenance dredging still must be employed; however, disposal of these dredged spoils is also a problem compounded by the difficulty in defining "acceptable" spoil for appropriate disposal sites.

Because of the many different types of dredging and disposal techniques, the different types of dredged material involved, and the great diversity of estuarine environments, present chemical indices for classifying dredged material must be expanded from simple numerical values for adequate nationwide application.

The conference participants advise that criteria for classification of dredged materials should not be based on concentrations of contaminants—neither total concentrations, nor reactive fractions. Rather the guidelines should be based on the total amounts of contaminants actually available for biological uptake—i.e. the concentration of the reactive fractions multiplied by the quantity of material to be dredged for any particular project. The suite of biological contaminants considered must be extended to cover all potentially toxic substances and pathogenic organisms.

NUTRIENTS

Most estuarine ecosystems are considered natural nutrient storehouses. When the capacity of estuaries to assimilate nutrients is exceeded, over-abundance of nutrients can cause nuisance accumulations of algae and rooted plants resulting in degradation of water quality. Natural sources of nutrients are mainly from upland drainage, while freshwater streams are a source of dissolved and particulate forms of nutrients. Major manmade point sources of high nutrient concentrations include domestic sewage and industrial wastes. Non-point sources typified by farms, forests, and urban runoff provide a high net yield of nutrients, adding significantly to the total. More work is required to define the relative importance of point and non-point nutrient sources as an aid in management control decisions.

A realistic nutrient management program should be based on factors that control the individual capacities of estuaries to assimilate nutrient inputs. These factors include physical processes such as the rate of flushing and biological processes such as nutrient cycling. A countrywide application of standards to control maximum permissible nutrient concentrations may be a counterproductive approach, because estuaries are highly diverse in their assimilative capacity.

Nitrogen and phosphorus are considered the most important nutrients (see Fig. 4), but their relative influence varies within an estuary, both spatially and temporally. Some geographical areas (notably Alaska) are relatively free of nutrient problems, but complacency can lead to future complications as experienced in many areas of the coterminous states and isolated estuaries of Hawaii.

Denitrification-nitrification, natural ecological filters (marshes and farm green belts), methods of fertilizer application, and processing of urban runoff are important research areas; however, drainage basin needs must be dealt with on a regional or individual basis.

INDUSTRIALIZATION EFFECTS

As the United States evolved into an industrialized society, our ports became the hubs of industrial activity in coastal regions. We now find ourselves with major industrial centers dependent on water transportation but located on estuaries neither deep enough for modern ships, nor large enough to assimilate associated wastes. At the same time these estuaries are incredibly valuable as a biological-recreational natural resource.

Industry depends on the estuary for waterborne transportation, for process water, or for products derived from estuarine waters or bottom sediments. Refineries and petrochemical plants, crude oil handling, power utilities, iron and steel production, paper manufacturing and sand and gravel extraction are the more important industries, most of which project increased production during the next several decades. Up to the present time, control of industrial effluents has been through the adoption of water quality standards and/or daily load limitations.

Another equally important consideration requires that we reduce the impact of industrial pollution in our estuaries by assisting industrial centers to find new, more environmentally acceptable sites. Regional groups must initiate work on the identification of the areas that can better accept the industrial wastes now discharged into our estuaries. The Coastal Zone Management Act, P.L. 92-583, may serve as an excellent vehicle to achieve this long-term objective.

POWER PLANT EFFECTS

Electrical energy production from the steam electric station (SES) industry results in the need to dissipate large quantities of heat. On the average,

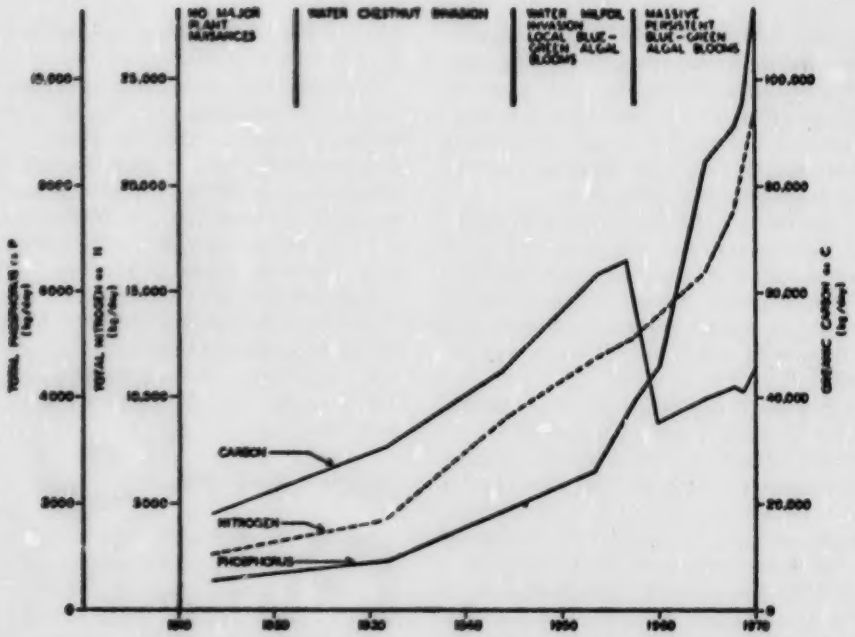


FIGURE 4.—Phosphorus, nitrogen and organic carbon in the upper Potomac River from 1913–70. The top line gives plant nuisances (from Jaworski, Lear and Villa, 1972, Fig. 7).

for every 1 megawatt of electricity produced, 1.7 megawatts of heat are rejected by an SES. This corresponds roughly to a 33 percent energy conversion efficiency for a typical fossil fuel plant. Efficiency of new fossil units is somewhat better, about 40 percent, while nuclear units achieve efficiencies around 32 percent.

Eventually, all of this heat must enter the atmosphere. Due to its large heat capacity water traditionally has been the "middle man" used to carry away the heat. Water requirements for a single power plant installation have increased greatly in the last decade, due primarily to the increased size of new plants.

Research has documented a number of undesirable site-specific, environmental and socio-economic impacts from SES operations. These impacts have been produced by a multiplicity of factors in addition to temperature. The following factors have been identified:

1. Temperature
2. Heavy metals leached from the power plant heat exchangers
3. Biocides used to prevent fouling of the heat exchangers
4. Changes produced by the effect of large volumes of water being discharged at high speeds.
5. Pumped-entrainment, pumped-entrapment problems.

Experience has indicated that at any given site, one design or operating feature may be responsible for the most undesirable effects while at a different site an entirely different design or operating feature is the problem. To achieve the best solutions and most effectively address the recognized problems, the minimal acceptable impact must be determined.

In order to quantify any undesirable changes and assess impacts, a standardized methodology for measurement and evaluation must be developed and used. These quantitative effects and predictions must also be considered from a cost-benefit standpoint. Such predictions, incorporated into an economic model, would provide a powerful tool for decision makers. The data also must be readily retrievable or the major portion of its usefulness will be lost. These step-by-step methodologies must be designed to achieve siting and operational procedures with the best environmental and socio-economic compatibilities (Fig. 5).

OTHER POLLUTANTS

A toxicant is any compound present in sufficient concentration to interfere with normal biological

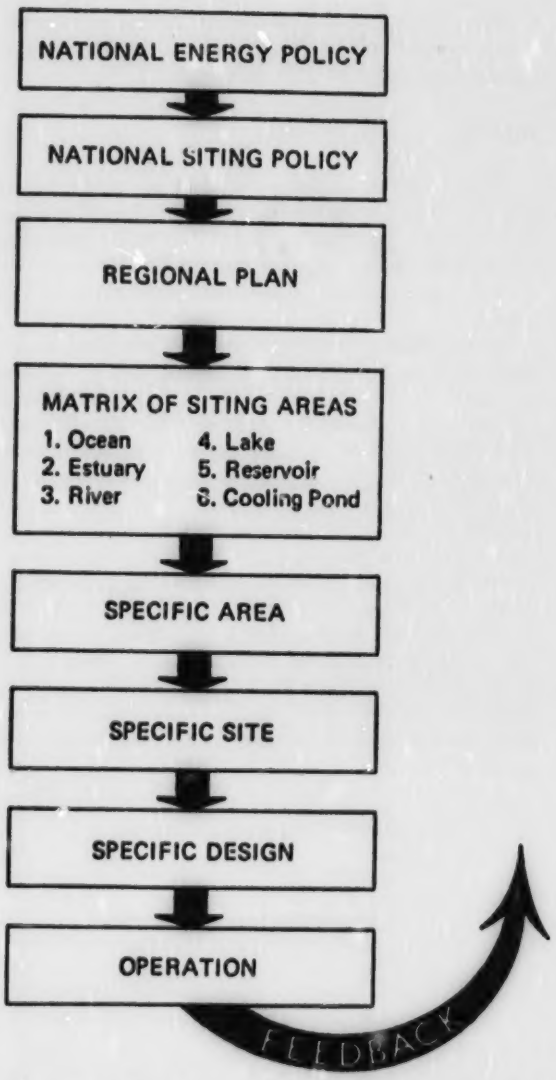


FIGURE 5.—Flow diagram for power plant siting considerations (after Committee on Power Plant Siting, 1972).

functions. One of the major toxicant groups, the organochlorine compounds, enters the estuarine environment primarily as a result of pest and weed control activities. Recent restrictions imposed on specific pesticides have triggered increased rates of new herbicide and pesticide development and use. Unfortunately, the result has been that the production and application of these organochlorides has outpaced research to identify their harmful effects.

Additionally, the significance of organochlorine compounds resulting from the use of chlorine as an antifouling biocide or as a disinfectant in waste treatment still represents an area requiring additional research effort.

Another group of toxicants is represented by petroleum products which include a wide variety of complex substances with an equally wide variety of impacts on estuarine systems (Figure 6). These impacts, aside from obvious aesthetic effects, range from immediate smothering to more subtle, chronic genetic modification of marine organisms. The estuary is most vulnerable to extreme impacts from petroleum because of bioaccumulation through the food chain.

In addition, oils act to concentrate other pollutants such as metals and pesticides, thereby increasing the ecological hazards. Field studies must be done in conjunction with laboratory investigations to determine the importance of these synergistic effects.

The potential threat of carcinogenic petroleum substances transmitted into the human food chain from contaminated seafood products remains to be scientifically demonstrated. The rates of transfer and long range fate and effect of water soluble components of petroleum are also poorly known.

Metals, too, pose complex problems in marine ecosystems, especially the estuaries. Although the sediments can sometimes act as a sink for entrapment of metals, many times man's activities, dredging for example, release metals back into the marine ecosystem potentially contaminating fisheries' resources and possibly entering the human food chain.

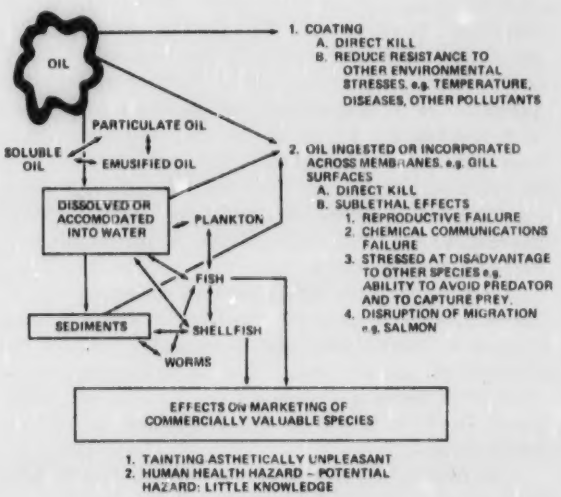

OIL
1. COATING
A. DIRECT KILL
B. REDUCE RESISTANCE TO OTHER ENVIRONMENTAL STRESSES, e.g. TEMPERATURE, DISEASES, OTHER POLLUTANTS
PARTICULATE OIL
SOLUBLE OIL
EMUSIFIED OIL
2. OIL INGESTED OR INCORPORATED ACROSS MEMBRANES, e.g. GILL SURFACES
A. DIRECT KILL
B. SUBLETHAL EFFECTS
1. REPRODUCTIVE FAILURE
2. CHEMICAL COMMUNICATIONS FAILURE
3. STRESSED AT DISADVANTAGE TO OTHER SPECIES e.g. ABILITY TO AVOID PREDATOR AND TO CAPTURE PREY.
4. DISRUPTION OF MIGRATION e.g. SALMON
DISSOLVED OR ACCOMODATED INTO WATER
PLANKTON
FISH
SEDIMENTS
SHELLFISH
WORMS
EFFECTS ON MARKETING OF COMMERCIALLY VALUABLE SPECIES
1. TAINTING ASTHETICALLY UNPLEASANT
2. HUMAN HEALTH HAZARD – POTENTIAL HAZARD: LITTLE KNOWLEDGE

FIGURE 6.—Pathways of oil incorporation into marine life and effects on marine life.

Fate and effect studies of metals and toxic compounds must be complemented with effective monitoring efforts in the marine environment for conclusive results. Only then can "safe levels" be established for elements in sediments, sludges, effluents, and edible species.

RESEARCH APPLICATIONS

Since microbial indicators are an "early-warning" system of changes in an ecosystem, presently known microbes should be more efficiently utilized while additional indicator organisms are investigated. Early or chronic environmental effects may be detectable if the microbial indicators are employed wisely and carefully. Increased emphasis should be placed on the development of methods for the direct measurement of pathogens. Combinations of indicator organisms might be employed. The advantages and disadvantages of each indicator organism should be determined so that each may be applied more intelligently to environmental assessment. This is only one facet of a complex problem involving such mechanisms as genetic transfer of resistance factors to potential human pathogens. Additionally, improved methods for virus isolation and identification and an understanding of virus survival in estuarine and coastal waters and sediments is required to determine their usefulness as indicators.

Another aspect of understanding estuarine systems involves identifying the interrelationship of the physical, biological and chemical processes within the system. Once understood, incorporation of these factors into numerical models would allow the prediction of trends and the effect of various abatement procedures, along with the establishment of appropriate monitoring sites. Unfortunately, at present our computational capabilities far exceed our knowledge of many of the required input parameters. Much research, therefore, is necessary in the area of the fundamental processes for characterization in the models. Short-term efforts should be directed toward field testing of the validity of existing models.

Assessment of the significance of persistent chemical residues in estuaries necessitates monitoring their existence, magnitude, and seasonality in the environment. At the same time, information on the effects of various chemicals on significant species must be determined under controlled laboratory conditions.

The data of systematics form the essential foundation of all other biological disciplines, but the inadequate number of taxonomists in the country is crucial. Thus it is important to support and encourage further development of taxonomists while carefully conserving the human and material systematic resources already existing.

PORTS

Ports must meet environmental demands during a period when they are faced with abrupt changes in terminal design and operations. While increased costs affect the economic productivity of our ports, port development will affect estuarine environmental quality.

An abundance of legislation with resulting guidelines, policies and regulations, is specifically focused on port and estuarine areas. In fact, 53 federal agencies and bureaus administer the 69 different port-related activities. This partition of administrative responsibility can require up to 550 individual steps in a permitting procedure. This tedious permitting process often causes confusion, delays and additional expense.

Studies indicate marked increase in port traffic, as shown in Figure 7. This fact, coupled with changes in ship and terminal design has increased the need for dredging with its associated environmental impacts. Therefore, environmental concerns associated with ports are increasing and a study of the regional port concept and the impact of offshore deepwater ports is essential.

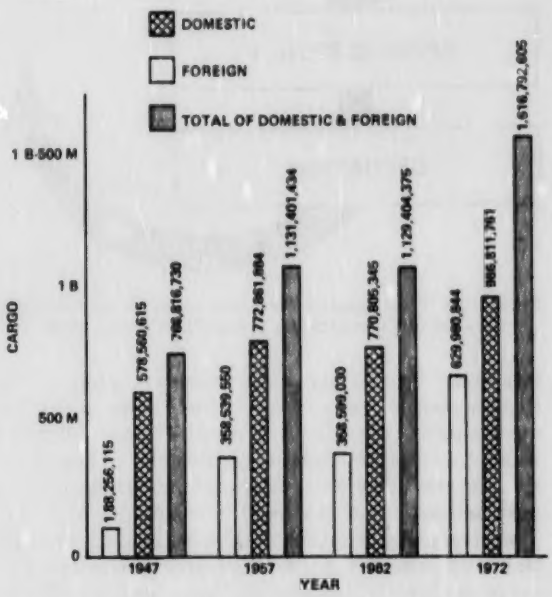


FIGURE 7.—Waterborne commerce in U.S., calendar years 1947–72 in million of tons (2,000 lbs.).

The participants and attendees at the conference expressed appreciation of the importance of the National Environmental Policy Act and the value of the environmental impact statement required therein. However, the following administrative areas were identified as needing clarification:

1. Permit application process—eliminate duplication of effort for the applicant.
2. Coordination among agencies administering the permitting program
3. Analysis of cost-benefit relationship—evaluation of the economics and environmental impact.

Where ports and ships are involved and the issue is clean water, the continuing problem involves proper disposal of ship generated oily waste, ballast water, and sanitary waste. Additionally, oil spills plague port operations and continue to degrade estuarine ecology. This situation will continue so long as vessels transport petroleum products within the estuarine area. In spite of efforts to regulate vessel traffic and train oil spill response teams, more research on methods and operational procedures for spill prevention and control is necessary, including the development of criteria for disposal of collected oil spill residues.

THE PUBLIC'S ROLE

An important aspect of the total effort in decreasing estuarine pollution is the active participation of the public. They not only are an integral part of any attempt to maintain the health and usefulness of estuaries, but also their health and welfare are the keystone on which the entire anti-pollution program is constructed.

The public performs three important functions in support of the estuarine environmental program. The first of these is to make their wants and needs known to those who can translate these requirements into action. The second is to help in the setting of priorities in the use of estuarine resources. The third is to accept the role of responsible citizens in reporting violations to the proper authorities and demanding appropriate response.

Two basic problems face the public. One is in the area of education and communication, while the other involves money. However, most public interest groups seem to be able to raise some funds when an important issue develops. Educating the public to the important issues may be the greater problem, since some of the issues are not well understood.

LEGAL ASPECTS

Over the past decade, the population of the United States has been rapidly shifting to the coastal areas of the nation. This movement, coupled with changing life patterns and progressive industrialization, urbanization, and development have influenced the quality of estuaries along much of the coastal margin. Efforts should be made to develop a set of national population distribution guidelines which would serve as a framework for regional, state, and local planning and development of land use management.

An improved level of coordination and planning among all levels of government could be effected by the establishment of a federal interdepartmental estuarine task force, conceivably as an adjunct to the federal coordination responsibilities of the Department of Commerce as provided for within the U.S. Coastal Zone Management Act. This task force would be expected to identify existing federal laws and policies affecting estuarine management and to synthesize them into a single federal policy for uniform application throughout the federal establishment.

This is especially true with respect to the present method of granting permits. A thorough examination of the present system should be implemented with an eye to the possible substitution of an interagency-state-federal panel that reviews the permits at all activity levels simultaneously.

The task force should further examine the current administratively established federal wetland policy and determine the need for legislative programs for wetland protection applicable to all federal activities, grants-in-aid and regulatory programs. Investigation should be made of the need for more specific legislation to provide federal impact aid assistance to coastal states, primarily in minimizing adverse environmental effects and providing some degree of control over the associated social and economic impact caused by the development of federal energy resources.

Concurrently, effective research and analytical support must be continued. This could still come from private institutions which have developed expertise on the dynamics of entire estuarine systems, or specific portions, and are thus in a position to present specific information on proposed projects. The regulatory agencies, however, should not be entirely dependent on the presentation and analysis of facts by outside parties. There also should be a continuing use of regulatory agency laboratories to produce an articulate program for the protection of estuarine systems.

ESTUARINE ECONOMICS

One aspect of management resulting in continued degradation of the estuarine environment is that the major portion of the estuary is common property. Since there is no individual ownership, there is no individual responsibility for protection and each user tends to consider his needs to the complete disregard of all other users. This situation can be improved by establishing an appropriate set of controls to bring the private costs of using estuarine resources into line with their social costs, thus preventing the estuary from being abused and overstressed.

An effective set of management techniques can be established by applying environmental standards. Implementation could be effected by either rezoning or by legal regulations and ordinances. Another possibility, however is to levy an emission charge. It can be demonstrated that the establishment of an appropriate level of emission charge is a potentially effective device for limiting the discharge of waste residuals into the estuary. A clear understanding that the polluter must pay in proportion to the amount of waste discharged is a strong incentive to prevention of damage.

A national policy on estuarine management is based upon the principle that the federal government establishes minimum environmental standards, but that local areas should be encouraged to establish environmental quality standards more stringent than the federal minimum. In keeping with this premise an attempt should be made to restrain irreversible estuarine development and to keep open as many options as possible for the future. Changing technology plus increasing demand for recreation areas will probably increase the future value of unspoiled recreational resources and reduce the present value of technology-intensive activities.

The value of estuaries to U.S. commercial and sport fisheries cannot be overestimated. Despite this important life support function, estuaries have lost more than 7 percent of their fish and wildlife habitat to commercial and housing development over the last two decades. In many coastal areas these developments proceeded without any evaluation of the socio-economic impact. Examination of the large number of estimates of commercial and recreational benefits associated with U.S. estuaries, reveals that practically all are conceptually invalid since they measure private rather than public welfare gains. It is misleading and unjustified from the perspective of economic theory to value estuarine resources solely in terms of market prices and not the public welfare cost.

CONCLUDING REMARKS

One of the products of the Federal Water Pollution Control Act, Amendments of 1972, is the National Pollution Discharge Elimination System, a permit system designed to control the flow of harmful wastes into the nation's waters and eliminate the introduction of all pollutants by 1985. Because the issuance of permits has begun only recently, and since all permits contain compliance schedules to reduce waste flows, no evaluation can be made at this time of the immediate impact of this program.

Of equal significance in this nation's effort to control the degradation of estuarine areas is the development and implementation of coastal zone management programs and procedures. This course of action has been effective in certain areas, but again, due to the recency of the program, there is not enough information available to quantitatively evaluate its impact.

To ensure that environmental protection efforts initiated over the past decade retain public support, the impact of the programs must be well publicized with concrete, understandable evidence. Aggressive educational programs, using all available media, must be recognized as a fundamental and top-priority need. The wide gap between science and public policy in all environmental matters is most likely to be closed, or at least narrowed, by an educated and public-spirited constituency, oriented logically rather than emotionally toward environmental management.

The general consensus of the workshop was that uniform application of water quality standards is impractical and from an economic point of view, undesirable. The participants support the viewpoint that water quality standards, when developed from existing criteria and information, should be based on specific locational parameters. These should include important biological species, climatological and hydrological features, hydrodynamic characteristics of estuaries, and the existing quality of the environment.

In order to develop a multiple-use management program within an estuarine area, it is essential that the impact of pollution on one use be evaluated as it affects other possible uses of the area. Figure 8 presents, in general fashion, a description of impacts arising from multiple usage. The table is intended as a management tool strictly from the standpoint of making early decisions with regard to evaluating potential usage of an estuarine area and defining some of the possible conflicts arising therefrom. It could also assist significantly in the development

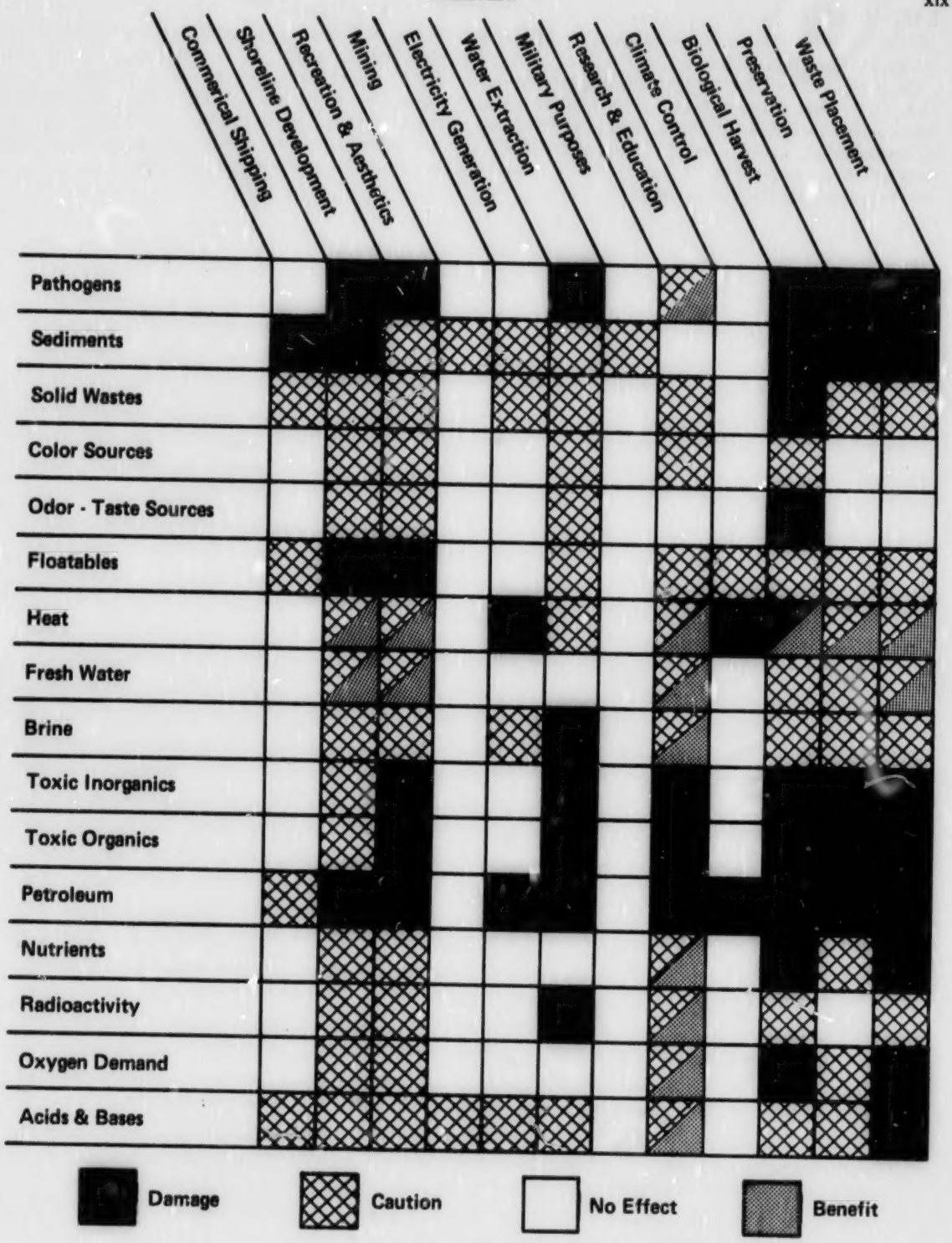


FIGURE 8.—Probable effects of pollutants.

of adequate water quality standards specific to a geographic location.

In the final analysis, the participants agreed that the Nation has been partially successful over the past 5-year period in retarding degradation of our estuarine zone. This has largely been accomplished through the application of new waste treatment technologies, and the implementation of newly written environmental regulations, standards, criteria and guidelines at both the state and federal levels. Every effort must now be made to assess current conditions and capabilities and to use potential resources and existing legislative tools to effect a national program for the prevention, reduction, and elimination of pollution in estuaries.

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ESTUARINE SYSTEMS

RESOURCE MANAGEMENT AND ESTUARINE FUNCTION WITH APPLICATION TO THE APALACHICOLA DRAINAGE SYSTEM

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ABSTRACT

Problems encountered in the management of an estuarine system in north Florida are discussed with respect to existing programs and laws in Florida. The often difficult decisions concerning resource development depend on the availability of baseline scientific and socio-economic data. Information is needed concerning the basic energy relationships of estuaries and the long-term effects of pollution on such systems. Realistic estuarine management practices involve an interdisciplinary approach at both the local and regional levels. Federal programs should be aimed at the translation of scientific information into the planned development of the entire drainage area of a given estuary. Based on successful and unsuccessful attempts of resource management in the Apalachicola drainage system, a generalized plan for estuarine development is given.

INTRODUCTION

Florida is presently a major growth area with respect to residential and tourist development. In addition to a population of more than 8,000,000 people, as many as 25,000,000 tourists visit this state each year. The population pressure, extreme in southern and western portions of the state, is concentrated in coastal areas where up to 75 percent of the people actually reside. Since estuarine areas provide the environmental basis for tourism, sports and commercial fisheries, and other related industries, there has been increasing interest, both at the local and regional level, in the development of workable resource management programs for the major drainage systems in Florida. Although there have been serious environmental problems in a number of estuaries such as Escambia Bay, Apalachee Bay, Hillsborough Bay, Tampa Bay, and Biscayne Bay, the variability of contributing factors (e. g., population size, industrialization, natural estuarine functions) has precluded a uniform approach to the problem. This paper will describe various problems of one estuarine system in north Florida, and, based on such experience, will attempt to develop a realistic approach to estuarine management.

The Apalachicola Drainage System

The Apalachicola system includes an area of over 19,500 square miles (Fig. 1), and is composed of four major rivers (Flint, Chattahoochee, Chipola, Apalachicola) and numerous creeks, streams, and marshes.

Drainage from Lake Seminole, an impounded reservoir formed from the Flint and Chattahoochee, becomes the Apalachicola River in Florida. This river, together with the Chipola, is the major source of fresh water for the Apalachicola Bay system (Fig. 2).

This is the largest river system in Florida with monthly mean discharge rates of approximately 25,000 cubic feet/second (cfs) and seasonal highs approaching 100,000 cfs. The drainage area includes a multifold complex of interlocking wetland systems (rivers, creeks, marshes, swamps) bordered by hardwood floodplain forests which provide habitats for a variety of organisms. The naturally high turbidity of the water reflects significant levels of nutrients and detritus that form the basis for the highly productive Apalachicola Bay system (Estabrook, 1973; Livingston et al., 1975A). During periods of high flow (usually late winter or early spring), submerged area becomes extensive due to river flooding. It is thought that massive exchanges of various elements occur between terrestrial and aquatic systems at this time. Nutrients and detritus are flushed into Apalachicola Bay (Estabrook, 1973; Livingston, 1974). The river influence can be detected 160 miles to the south in the Gulf of Mexico (Curl, 1959).

The Apalachicola Bay system, roughly 212 square miles, is a shallow lagoon-barrier island complex situated along an east-west axis. Around 500 square miles of swamps are located above the bay; approxi-

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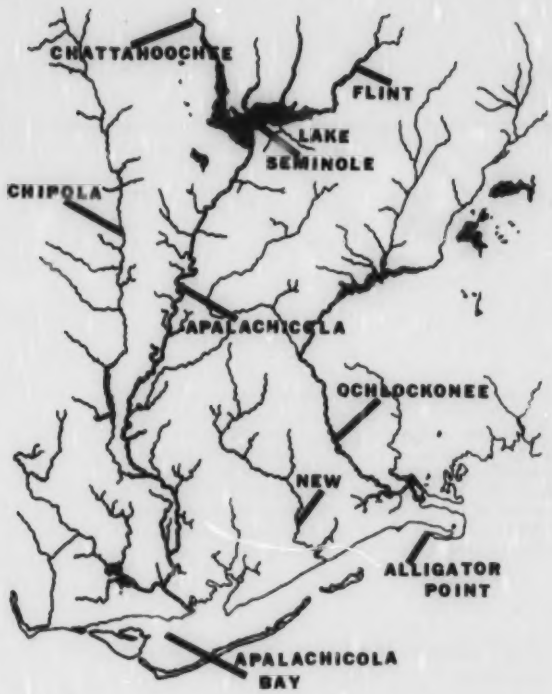


FIGURE 1.—The lower half of the Apalachicola drainage system showing the major rivers contributing to Apalachicola Bay in North Florida.

Table 1.—Representative organisms found in the Apalachicola Bay System

Fishes	Invertebrates
Gymnura micrura (Butterfly ray)	Crassostrea virginica (Oyster)
Dasyatis sabina (Atlantic stingray)	Callinectes sapidus (Blue crab)
Sphyrna tiburo (Bonnethead)	Penaeus aztecus (Brown shrimp)
Anchoa hepsetus (Striped anchovy)	Penaeus duorarum (Pink shrimp)
Arius felis (Sea catfish)	Penaeus setiferus (White shrimp)
Bagre marinus (Gafftopsail catfish)	Palaemonetes vulgaris
Eucinostomus gula (Silver Jenny)	Palaemonetes pugio
Eucinostomus argenteus (Spotfin mojarra)	Rhithropanopeus harrisii
Mugil Cephalus (Striped mullet)	Neopanope texana
Lagodon rhomboides (Pinfish)	Tozeuma carolinense
Bairdiella chrysura (Silver perch)	Periclimenes longicaudatus
Micropogon undulatus (Atlantic croaker)	Palaemonetes intermedius
Leiostomus xanthurus (Spot)	Pagurus bonairensis
Cynoscion arenarius (Sand seatrout)	
Cynoscion nebulosus (Spotted seatrout)	
Sciaenops ocellata (Red drum)	
Brevoortia patronus (Gulf menhaden)	
Menticirrhus americanus (Southern kingfish)	
Orthopristis chrysoptera (Pigfish)	
Lagodon rhomboides (Pinfish)	
Centropristis melana (Black sea bass)	
Lucania parva (Rainwater killifish)	
Synodus foetens (Inshore lizardfish)	
Lutjanus griseus (Gray snapper)	
Monocanthus hispidus (Planehead filefish)	
Syngnathus scovelli (Gulf pipefish)	
Syngnathus floridae (Dusky pipefish)	
Syngnathus louisianae (Chain pipefish)	
Sphoeroides nephelus (Southern puffer)	
Lactophrys quadricornis (Scrawled cowfish)	
Chilomycterus schoepfi (Striped burrfish)	
Paralichthys albigutta (Gulf flounder)	
Paralichthys lethostigma (Southern flounder)	
Symphurus plagiusa (Blackcheek tonguefish)	
Prionotus tribulus (Bighead searobin)	
Caranx hippos (Crevalle Jack)	
Scomberomorus maculatus (Spanish mackeral)	
Microgobius gulosus (Clown goby)	
Gobiosoma robustum (Code goby)	
Hypsoblennius hentzi (Feather blenny)	

mately 20 square miles of marshes are associated with the bay. Much of this region is too wet in its natural state for traditional forms of agriculture without the use of diking, ditching, and draining. A series of barrier islands enclose the bay, and this thin line of land, together with the freshwater runoff from upland areas, provides the ecological basis for the very productive estuary (e. g., numerous oyster bars). The major connection of Apalachicola Bay with the Gulf of Mexico is St. George Sound, with lesser outlets consisting of a dredged pass (Sike's Cut) and two natural openings (Indian Pass, West Pass). The bay bottom consists of a sandy-shell mixture and silty sand (Menzel and Cake, 1969) with little development of benthic macrophyte growth.

Apalachicola Bay is a primary source of income for the people of Franklin County, Fla., (Colberg et al., 1968; Rockwood, 1973; Livingston et al., 1974A). A representative list of organisms, including various species of commercial and sport fishing importance, is shown in Table 1.

The Apalachicola oyster industry ranks high in the state (Table 2), and is the fifth most valuable fishery in Florida. It has been estimated that over 75 percent of the commercial landings for the county depend on species which utilize this estuary as a nursery or feeding ground (Menzel and Cake, 1969). Such organisms depend directly or indirectly on detritus, nutrient supplies, and reduced salinities provided by freshwater runoff. The entire watershed system is interconnected; the estuarine functions depend on upland drainage features and a complex series of energy exchanges and feedback reactions within the bay system itself.

FORMS OF POTENTIAL IMPACT

One of the important questions related to estuarine management concerns the long-term (chronic)

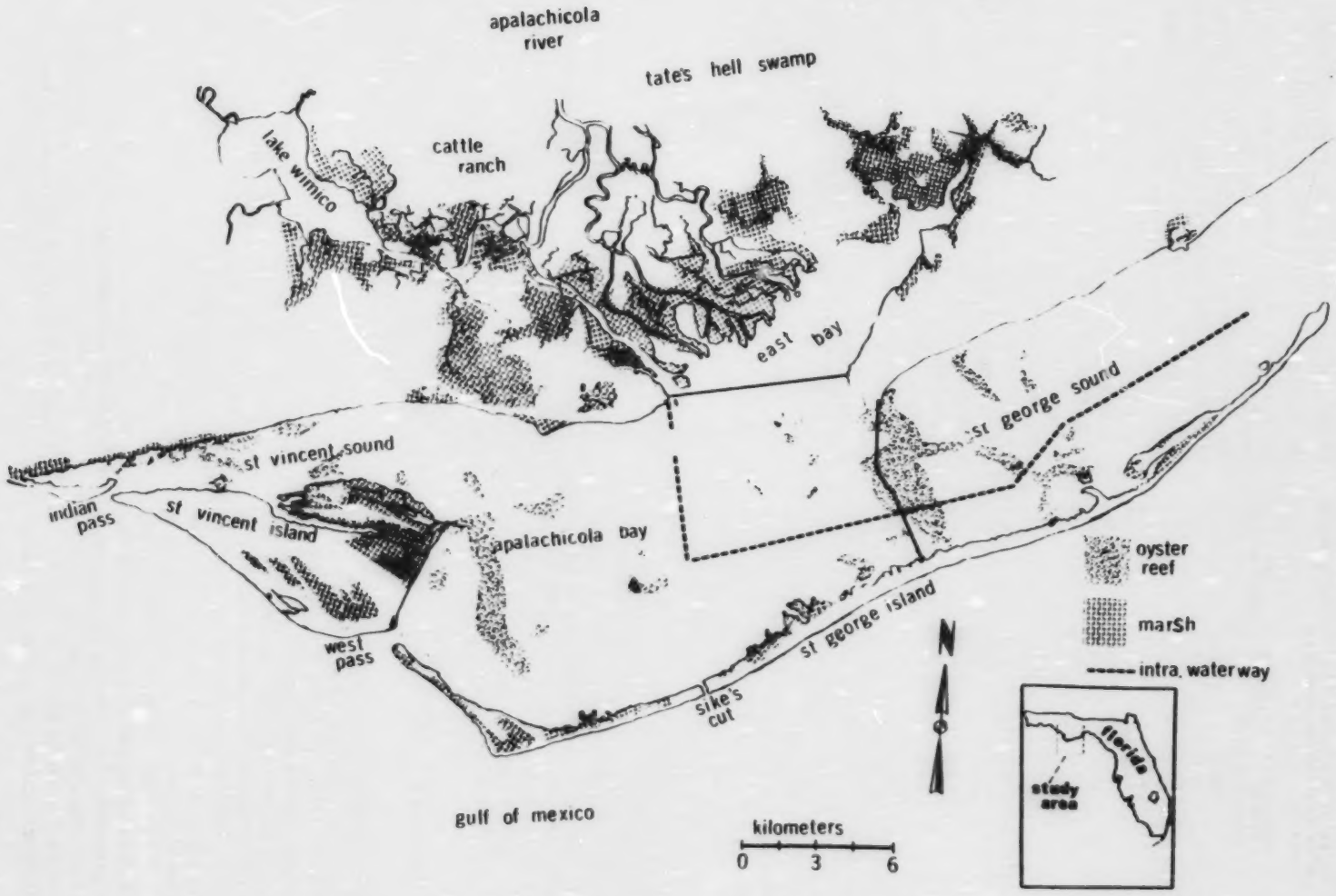


FIGURE 2.—The Apalachicola Bay system showing the distribution of major oyster bars, upland swamps and marshes.

Table 2.—Oyster landings in Franklin County and the State of Florida (1950–70) and percent contribution (County/State)

Year	Franklin County (1000 lbs)	State of Florida (1000 lbs)	Ratio County/State × 100
1950	696.0	895.2	77.7
1951	546.6	735.3	74.3
1952	451.1	563.0	80.1
1953	459.2	585.4	78.5
1954	553.9	685.5	80.8
1955	542.9	649.6	83.6
1956	722.0	888.7	81.2
1957	624.2	734.9	84.9
1958	713.2	824.7	86.5
1959	1,268.8	1,455.0	87.2
1960	1,744.8	1,975.4	88.3
1961	2,947.1	3,326.6	88.6
1962	4,366.7	5,019.8	87.0
1963	3,810.5	4,362.8	87.3
1964	2,252.4	2,885.1	78.1
1965	2,377.5	2,954.7	80.4
1966	3,809.9	4,291.9	88.8
1967	4,195.9	4,761.1	88.1
1968	4,825.7	5,568.8	86.7
1969	4,350.4	5,125.7	84.4
1970	3,044.4	3,786.5	80.4

effects of individual and collective upland development on estuarine systems. This includes toxic effects, habitat destruction, and changes in nutrient and detritus relationships. Synergism and interactions of pollutants with natural modifying factors such as temperature and salinity complicate evaluation of potential impact (Livingston et al., 1974b). The extreme variability from one estuary to another precludes broad generalizations concerning natural estuarine functions. Thus, it is generally recognized that each estuarine system should be approached on an individual basis with such factors as latitude, drainage area, river flow, offshore circulation, and depth taken into consideration.

Physical Alterations

Maintenance dredging has contributed to local habitat destruction, simplification of the fauna, and low productivity in some portions of the Apalachicola River (Cox, 1969, 1970; Cox and Auth, 1971, 1972, 1973). It is possible that dredging of the intracoastal waterway and the opening of Sike's Cut in Apalachicola Bay has altered salinity relationships by directing surface runoff out of the bay and by allowing saline (subsurface) water of gulf origin into the bay (Livingston, 1974). Such salinity increases can lead to reduction of oyster crops due to predation by organisms that are normally prevented entry to the bay because of low salinity (Menzel et al., 1957; Menzel et al., 1966).

Another concern is a proposal by the U.S. Army Corps of Engineers to improve the navigability of the Apalachicola River by the construction of a series of four dams. Serious questions have been raised concerning local habitat destruction by flooding, interruptions of migrations by anadromous fishes such as shad and striped bass, reduced nutrient and detritus flow, and alteration of the temperature and salinity regimes in Apalachicola Bay.

During the past three years, thousands of acres of swamps and marshes have been altered by various agricultural interests (Fig. 3).

About 10 miles up-river from the bay, a 33,000 acre cattle ranch has been established. This has involved clearing, ditching and draining the land and the construction of an extensive system of dikes to prevent periodic flooding (Fig. 4).

In addition to periodic pumping of turbid, low quality water into surrounding creeks, the natural interactions between terrestrial and aquatic systems

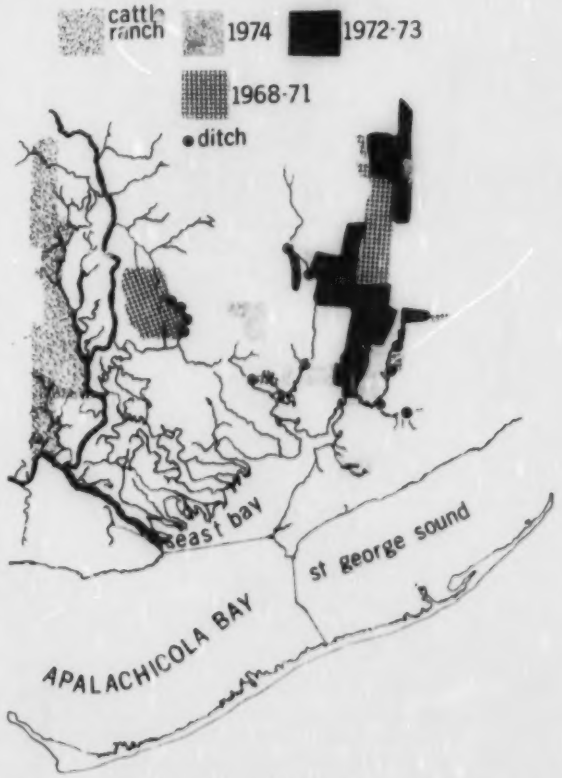
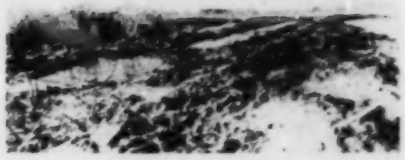


FIGURE 3.—Wetlands areas recently cleared by cattle and pulp mill interests in an attempt to utilize the lower Apalachicola valley for agricultural purposes. The lower portions of the cattle ranch have been cleared, ditched, and diked while pulp mill areas have been cleared, ditched, and drained into East Bay.

DRAINAGE DITCHES

DITCHED AREA



DIKE

FIGURE 4.—Cattle ranch activities include digging of an extensive system of drainage ditches and the diking of the lower portions of the property to prevent flooding.

have been interdicted. Recently, thousands of acres of upland timber above East Bay (Fig. 5) were clear-cut by local paper mills.

After removal of trees, the land is plowed, ditched, and drained into creeks that empty directly into the nursery areas of East Bay. During periods of heavy rainfall, highly colored water washes into the bay (Fig. 6). This water, characterized by low pH and altered physical and chemical characteristics, is avoided by shrimp in laboratory experiments (Livingston, 1974). This corresponds to reports by commercial fishermen that shrimp no longer enter areas of "black" water runoff. Questions remain concerning alterations in the salinity structure of the bay and long-term changes caused by the introduction of various chemical agents such as tannins, humates, and fertilizers.

Industrialization

The ultimate aim of dredging and damming the Apalachicola River is to provide a corridor for logistic support and maintenance of upland industrial interests in Florida, Georgia, and Alabama. According to a report by the Northwest Florida Development Council and Economic Development District (1974), the Apalachicola River could serve as a major functional transportation route for industrial concerns in Alabama and Georgia. A dam and lock system would be utilized and adjacent corridors would be strengthened; this would lead to increased barge traffic and expansion of industrial interests along the river. Plans for an industrial park just below the Woodruff Dam have been activated. According to the Tri-Rivers Waterway Development Association, over 5,000 jobs in Florida, Georgia, and Alabama are dependent on navigation along the Apalachicola-Chattahoochee-Flint waterway. These jobs are associated with paper mills, fertilizer factories, construction activities, sand and gravel operations, and barge facilities. By 1976, it is estimated that 1,700 new jobs will be created by such activities. Problems associated with increased turbidity and heavy metal concentrations, petrochemical spills, and municipal wastes could be anticipated with such industrialization.

Residential Development

St. George Island is an integral part of the Apalachicola Bay System (Fig. 7). Development of this barrier island is considered the most important single factor in the growth of Franklin County (Colberg et al., 1968). With the construction of a bridge connecting the island to the mainland, St. George has essentially been opened for development.

The Northwest Florida Development Council has proposed an expansion of the financial base of Franklin County by the development of a tourist/retirement community around Apalachicola Bay.

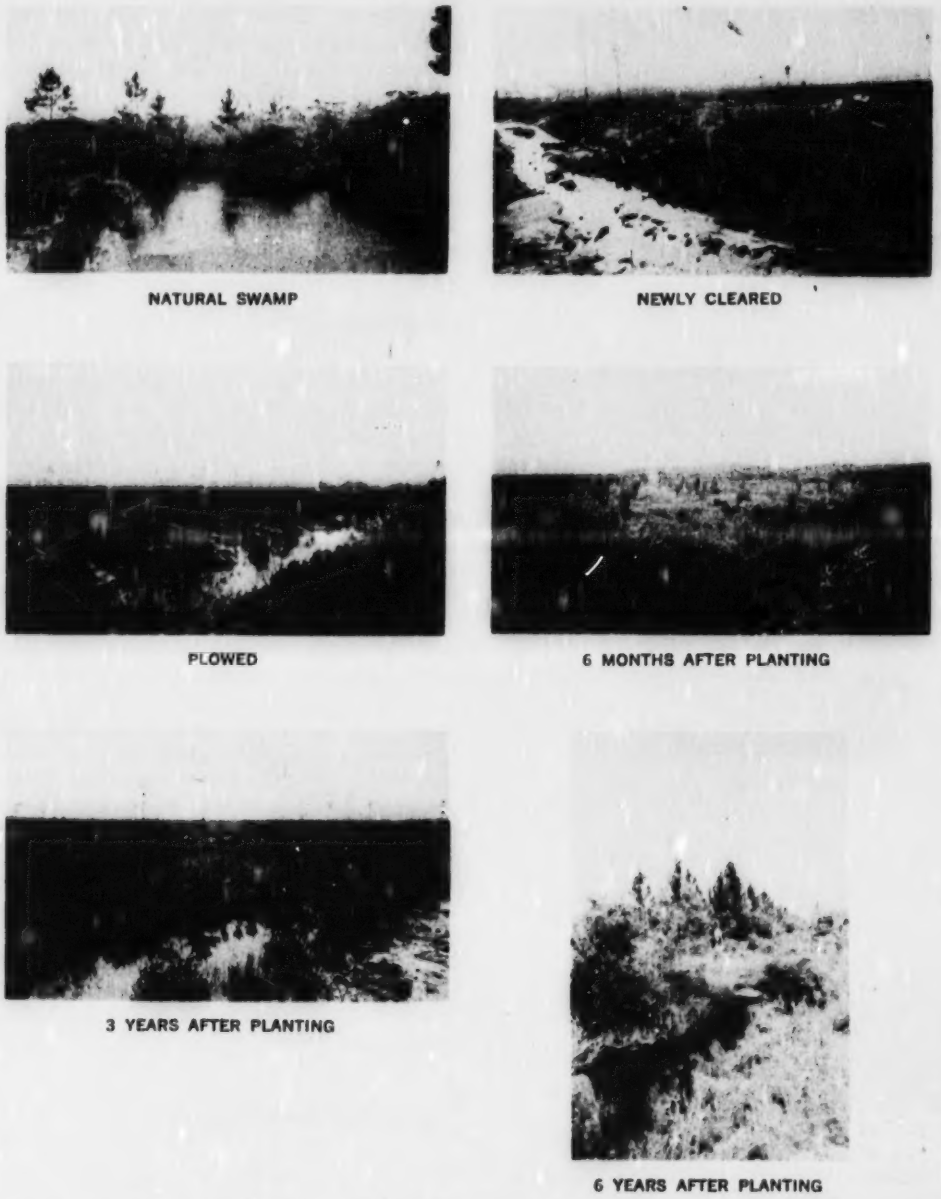


FIGURE 5.—Pulp mill activities in Tate's Hell swamp. Areas are cleared, ditched, plowed, and replanted with slash pine monocultures. Growing trees are fertilized periodically. Highly colored water, characterized by low pH, is drained directly into the bay from the cleared areas. The potential impact of such drainage on the bay organisms remains unknown.

However, the narrowness and relatively limited drainage capacity of St. George Island presents a difficult situation for residential development if the ecological integrity of the bay is to be maintained. The productive oyster beds proximal to the island in St. George Sound would be vulnerable to contamination from septic tank drainage, storm water runoff, and pesticides. Public health standards for approved oyster growing areas set a limiting (MPN) value of 70 for group coliform organisms. With

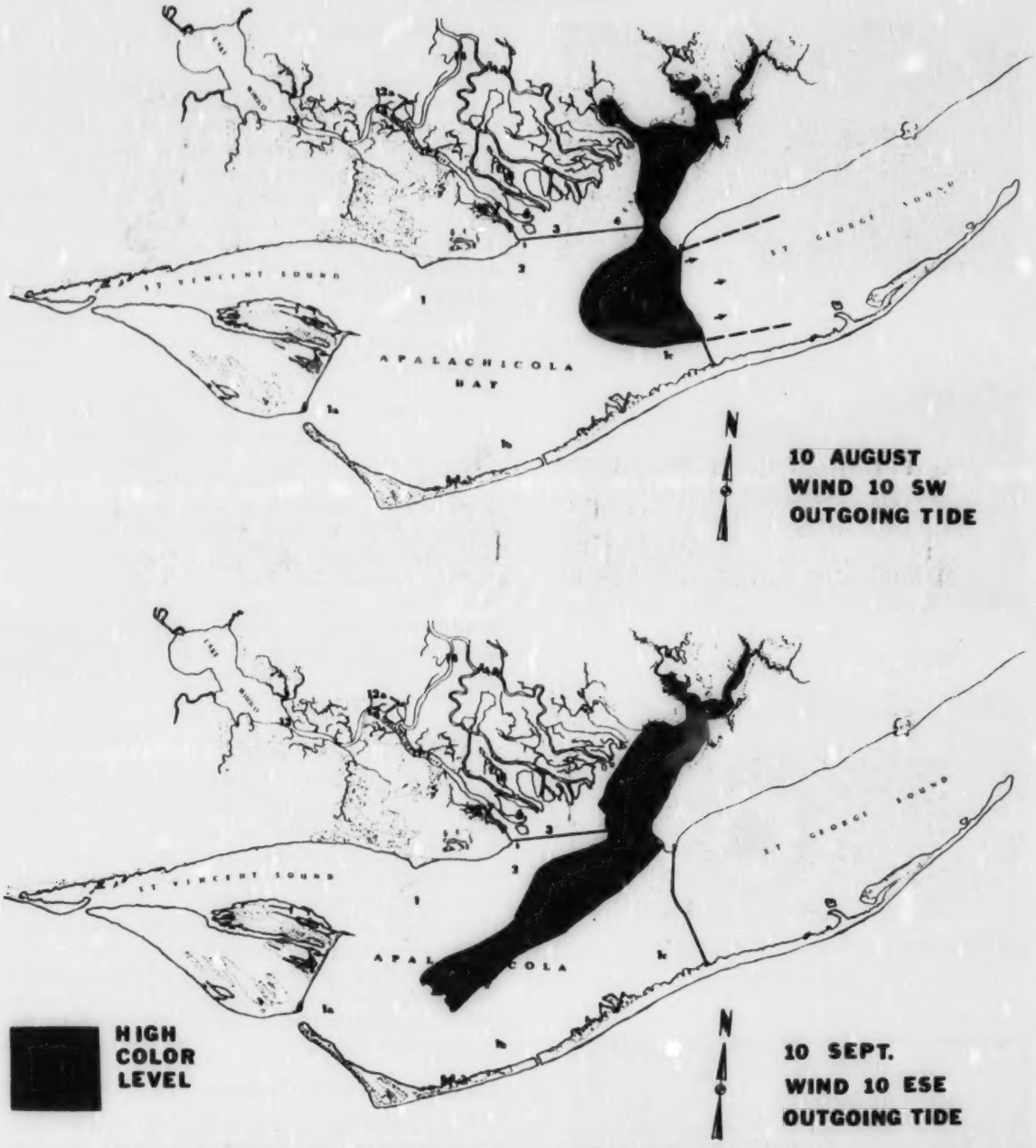
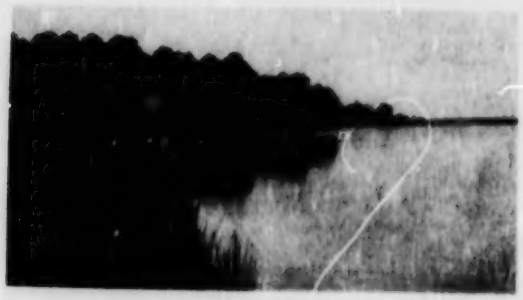


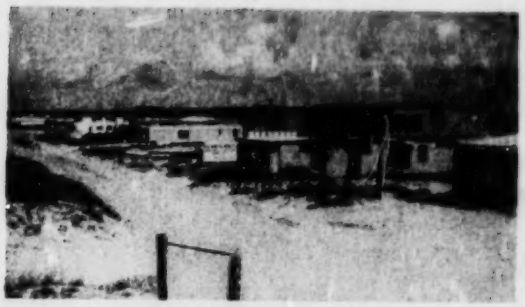
FIGURE 6.—Observations of drainage from the upland ditched areas in East Bay after periods of heavy rainfall. Highly colored water from drainage ditches can be traced as it moves into the bay.

increased numbers of people in the bay area, pest control (dogflies, sandflies, mosquitoes) would increasingly become a problem. Pesticide programs and other methods such as ditching and biological control (e.g., mosquito-eating fishes) would have to be developed as the population of the area increased. Tourist-oriented development is not without serious problems for the oyster-based economy of Franklin County. Before the population grows to an unmanageable size, strict controls of such development

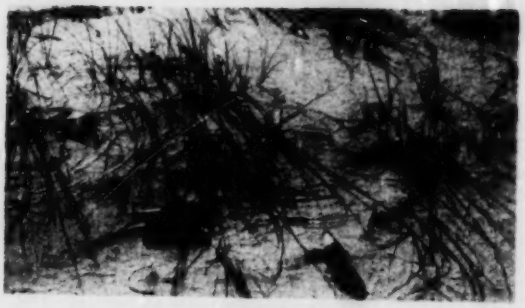
SOLID WASTE



NICK'S HOLE



DEVELOPMENT



BEACH

should be adopted if the seafood industry is to remain viable.

The Apalachicola drainage system is presently at a critical stage of development. In this respect, the magnitude and complexity of the social, economic, and environmental problems are typical of various other estuaries in the United States. As yet, Apalachicola Bay is relatively unpolluted. Studies have shown that there is relatively little contamination of the bay from pesticides and other forms of contamination (Livingston, 1974). Nutrients and phytoplankton studies have shown comparable levels of productivity with other areas of the Gulf of Mexico; there are no signs of cultural eutrophication (Estabrook, 1973; Livingston et al., 1974A). Oyster contamination appears to have remained stable over a considerable period with no significant difference between present coliform group MPN values and data taken during the 1940's (Livingston et al., 1974). The epibenthic fauna appear stable (Livingston, 1974). Overall, the Apalachicola drainage system represents an important natural resource that is coming under increasing developmental pressure. An equitable solution to the inevitable conflict over resource development would rest in a management program based on objective scientific investigations. Some approaches to this problem have been made through the Florida State University System Sea Grant Program.

ESTUARINE MANAGEMENT

A growing number of laws and administrative regulations are being designed to promote management and conservation of aquatic systems. The State of Florida has developed a sophisticated system of legal and administrative procedures regarding development in wetland and coastal areas. A list of environmental laws and regulations (federal and state) along with the agencies responsible for their implementation is shown in Table 3. Several of these laws have been used by Florida Sea Grant investigators in applying management practices to the Apalachicola system.

Land Conservation Program

The Florida Land Conservation Program involves the procurement of endangered lands by the state

FIGURE 7.—St. George Island: Solid waste disposal near the bay with increased residential development in already platted portions of the island. Such problems often accompany residential development of coastal areas. Marshes (Nick's Hole) and beaches are sensitive portions of island systems that should be protected from destructive land development practices.

without eminent domain power. During the course of a monitoring program in Apalachicola Bay it was found that during certain periods of excessive overflow of the Apalachicola River into associated wetland areas, considerable quantities of terrigenous detritus (leaves, branches, and so forth) were deposited in Apalachicola Bay (Livingston, 1974). Leaf matter from various types of trees that grow along the river (oak, pop ash, river birch, water hickory, et cetera) accumulated in certain areas of the bay. The importance of allochthonous detritus to other estuarine systems has been established (Darnell, 1961; Teal, 1962; Heald, 1969; Odum, 1971). Two

Table 3.—Partial annotated list of laws and regulations (federal and state) pertaining to environmental problems in navigable and tidal waters and the lands beneath them

1. Federal

A. Rivers and Harbors Act of 1899 (33 U.S. Code, Sections 401, 403, 404, 406–417)

Applies to filling, excavating, or altering navigable waterways, also regulates discharge of pollutants, refuse, and dredge spoils into navigable waters. U.S. Army Corps of Engineers is responsible for permitting (in cooperation with Florida Board of Trustees and Department of Pollution Control).

B. Federal Water Pollution Control Act (33 U.S. Code, Section 1141 et seq.) —amendments of 1972. (Title 33, U.S. Code, Section 1251 et seq.)

Aims to restore and maintain chemical, physical, and biological integrity of all waters of U.S. Calls for elimination of pollutant discharges by 1985 and achievement of water quality for protection and propagation of fish, shellfish, and wildlife by 1983. Responsible agencies include U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers, U.S. Coast Guard, with help from Florida Department of Pollution Control.

C. National Environmental Policy Act of 1969 (42 U.S. Code, Sections 4332, 4344)

Establishes environmental protection and restoration as national policy with provisions for generation of environmental impact statements concerning any actions of federal agencies that may impinge on the environment. The Council on Environmental Quality, established by NEPA, provides guidelines for such impact statements. U.S. Environmental Protection Agency is primary agency involved in enforcement although most federal, state, and local agencies operate within NEPA.

D. Marine Protection, Research and Sanctuaries Act of 1972 (33 U.S. Code, Section 1401 et seq.)

Concerned with protection of oceans from pollutants discharged from vessels including dredge spoils, chemicals, etc. Responsible agencies include U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

E. Fish and Wildlife Coordination Act of 1958 (16 U.S. Code, Section 661–666C)

Requires consideration of effects of work in navigable waters on fish and wildlife. U.S. Army of Engineers coordinates with other federal and state agencies.

F. Endangered Species Act of 1973 (Public Law 93–205)

Provides conservation measures for endangered and threatened species. Administrated by U.S. Department of the Interior.

2. State

A. Florida Air and Water Pollution Control Act (chapter 403, 011, Florida statutes)

Public policy to conserve quality of state air and waters, provided that no wastes are discharged into water without proper treatment, et cetera. Administered by the Florida Department of Pollution Control with help from the Division of Health of the Florida Department of Health and Rehabilitative Services.

B. Florida Water Resources Act of 1972 (chapter 373, Florida statutes)

Relating to all state waters (except with respect to water quality), conservation and control programs for management and conservation of such related resources (fish, wildlife, et cetera). Utilization of surface and ground water, prevention of damage by flooding, soil erosion, excessive drainage, et cetera. Administered by Florida Department of Natural Resources with delegation of powers to five regional water management districts. Presently involved in generation of a state water use plan.

C. Florida Environmental Land and Water Management Act of 1972 (chapter 380, Florida Statutes)

Establishment of an Area of Critical State Concern (ACSC) program and the developments of regional impact (DRI) evaluation process. Areas of critical concern qualify for such designation by having environmental, historical, or archeological importance, or being affected by major development. The purpose is to formulate state decisions establishing land and water management policies for the guidance and coordination of local decisions concerning growth and development. This does not apply to more than 5 percent of the land of Florida as an ACSC, and agricultural activities are exempt from its provisions. A DRI is a report filled out by the developer according to specified questions that are to be answered concerning the overall impact of the development on the region's environment, natural resources, economy, et cetera. The Division of State Planning, Department of Administration implements this act; review of DRI's are considered by the appropriate regional planning agency with the local government conferring final approval, approval with conditions, or denial. The overall purpose of this act is to promote the creation of principles to guide development on the local level within specified state-sanctioned guidelines so that any major development in a given area is compatible with the local environment.

D. Florida State Comprehensive Planning Act of 1972 (chapter 23, Florida Statutes)

Provides plan for long-term guidance for staff growth by establishing goals, objectives, and policies. This includes coordination of planning efforts among local, state, and federal agencies. Division of state planning is responsible for implementation of this act.

E. Land Conservation Act of 1972 (chapter 259, Florida Statutes)

Environmentally Endangered Lands Program (EEL Program) based on analysis of available ecological information to determine priorities of environmentally endangered land. An EEL plan will be developed to guide the purchase by the state of endangered lands. In such purchases, there is no eminent domain power to implement land acquisition; this precludes identification and priority listing of endangered lands. The choice between acquisition and regulation depends on level of protection necessary to achieve the desired environmental aims. Emphasis is on ecological significance, the importance of submerged lands, and appropriate evaluation. Administration is by the Department of Natural Resources with input from other state agencies and a panel of experts on environmental and planning concerns. This includes interagency planning and advisory committees with final approval by the Governor and cabinet.

F. Beach and Shore Preservation Act (chapter 161, Florida Statutes)

Provides for beach nourishment, erosion control, regulation of coastal construction, and establishment of setback lines along beaches. Administered by the Department of Natural Resources.

3. Applications to Apalachicola Bay

A. Resolutions designating Apalachicola Bay as an aquatic preserve in accordance with management policies governing such areas.

B. St. Vincent Island is a National Wildlife Refuge that is controlled by the Department of Interior.

C. Endangered lands along the Apalachicola River have been approved for purchase by the Governor and Cabinet.

D. The area is bordered by the Apalachicola National Forest and several parks.

E. A coastal setback line (state) has been established for the gulf side of St. George Island. A county wide setback line (Franklin County) for all lands bordering aquatic areas is presently under consideration.

F. The Apalachicola drainage system is presently under consideration for designation as an Area of Critical State Concern.

years of experiments were carried out in which baskets of leaves were dropped into different parts of the bay and checked regularly for possible association with assemblages of estuarine organisms (Livingston, 1974). The leaves were found to be associated with various food webs in the bay. Although little was known concerning the exact origin of the leaf matter and its actual quantitative contribution to the bay energy budget, the potential importance of such a source had to be recognized.

Deciduous hardwood forests border the river; such swamps, in addition to providing a habitat for a wide variety of terrestrial organisms, are considered to be a focal point for exchanges of nutrients and detritus which eventually become part of the estuarine energy system. In addition to serving as filters for various inorganic and organic substances, such swamps are thus an integral part of the ecological balance of the lower Apalachicola wetlands. Activities such as clear-cutting, ditching, diking, and draining could interrupt such exchanges; in addition, changes in the form of available leaf matter could have an effect on the water and energy budgets of local aquatic areas as well as downstream estuarine systems. This has been shown in various studies (Egglishaw and Mackay, 1967; Woodall and Wallace, 1972). Recent evidence (Swank and Douglass, 1974) indicates that replacement of deciduous forests by coniferous monocultures can seriously alter the water budget of upland areas. Woodall and Wallace (1972) considered that watershed vegetation is a major determinant of aquatic species composition and abundance.

Comprehensive quantitative determination of nutrient and detritus exchanges in bay systems is not available; the nutrient-detritus budget of the Apalachicola bay system remains unknown. However, the leaf data supplied by the Florida Sea Grant project (Livingston, 1974) provided the scientific support for the purchase of $4.4 million of river swamp along the lower Apalachicola river (Fig. 8). Soil analysis contributed to the identification of flooded areas; this was used in the determination of the endangered areas.

At this time, while much of the land is designated for immediate purchase, negotiations are under way for other lands that border the Apalachicola river (Fig. 8). State agencies are presently considering the trade of less sensitive upland areas (above the drainage system) for hardwood swamps (owned by pulp mills) bordering the river. In this way, under the Land Conservation Act of 1972, sensitive portions of the lower Apalachicola river valley will eventually be set aside by the state of Florida as a preservation area to remain in a natural state. Some

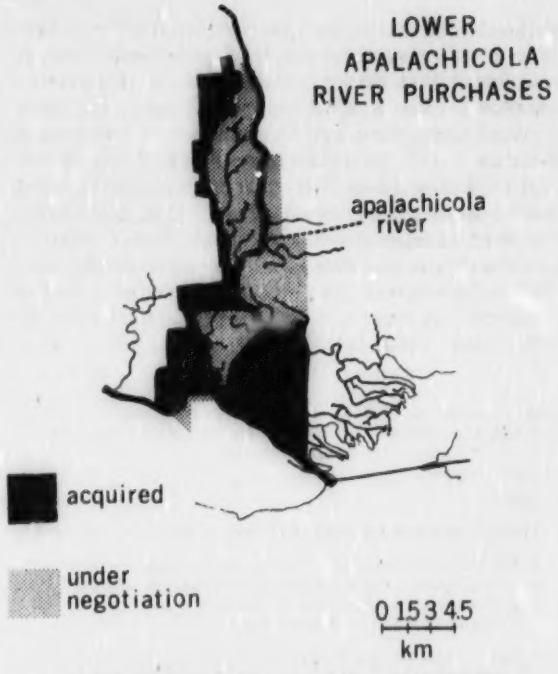


FIGURE 8.—Purchases of portions of the lower Apalachicola River basin by the state of Florida under the Land Conservation Act of 1972. Those listed as "acquired" have been approved by the Florida Cabinet and now await resolution of legal boundary lines and actual purchase. Those listed "under negotiation" are still being considered as part of a trade with less sensitive upland areas.

difficulties have been experienced with this program. Removal of the land from local tax rolls has stirred some opposition. Without eminent domain powers, bargaining can become difficult, with higher prices, bureaucratic confusion and delays often accompanying the deliberations. On the whole, however, this program has been successfully carried out and is presently a powerful (though limited) method for the preservation of sensitive endangered lands.

Areas of Critical State Concern

The Apalachicola drainage system is presently being considered for designation as an area of critical state concern (Table 3). Although this would allow more state involvement in the management of the system with respect to specific forms of development such as municipal waste, drainage programs, and industrialization, agricultural practices such as massive clearing and drainage operations (cattle ranch, pulp mill operations, et cetera), and fertilization programs would remain exempt from control. How-

ever, the ACSC program and the DRI Evaluation process (Table 3) have promoted an effective means of control at the local level. In addition to the provision of a legal means of implementation of county-wide planning programs, the expertise of various state agencies is made available to local governments. All too often, such governing bodies are inexperienced in zoning and subdivision regulations that promote orderly growth. Franklin County, for instance, has recently taken steps in this direction by soliciting and passing a county-wide plan. In addition, at the urging of Sea Grant investigators and local seafood interests, a group is presently looking into the development of county zoning regulations to promote protection of the bay system. Such activities are not without considerable opposition. Reaction includes demands for reimbursement by property owners in such state or county controlled areas, requests for more specific scientific information concerning designation of critical areas, and the establishment of tax relief provisions for counties with high percentages of setback lines and critical lands.

Negotiations With Individual Developers

Another approach has been attempted by the Florida Sea Grant Program (Livingston, 1974). Sea Grant scientists are presently initiating a research effort in conjunction with pulp mill interests (the Buckeye Cellulose Corp.). A cooperative research program has been developed whereby all clear-cutting, roadbuilding, and drainage operations in the East bay system have been suspended. In addition to indepth, long-term field monitoring operations in this area to determine potential impact (Livingston, 1974), experimental ecological research will be carried out in conjunction with a comprehensive terrestrial-aquatic sampling program. An experimental area will be cleared and ditched and the physicochemical and biological factors in adjacent areas will be continuously monitored to determine the potential impact of storm water runoff on the aquatic biota. Also, new ways of land utilization will be tested; this includes the setting aside of extensive fringe areas, direction of runoff to holding ponds before release into surrounding areas, and so forth. It must be pointed out that this is due in large part to the enlightened environmental policies of the Buckeye Cellulose Corp.; it does emphasize a growing willingness among private concerns to experiment with alternate methods of development when such efforts are based on objective scientific data. The importance of local contact should not be underestimated.

Barrier Island Development

The situation on St. George Island is a classical case of the dilemma of residential development within estuarine systems. St. George Island is one of three barrier islands that form the Apalachicola bay system (Fig. 2). The island is 30 miles long (7,340 acres of land; 1,200 acres of marshes) and averages less than ⅓ mile in width. It conforms in geological and biological terms to classical barrier island characteristics (Fig. 9) and is an integral part of the bay system (Livingston, 1974).

It is entirely surrounded by salt water, and any freshwater runoff comes entirely from rainfall which filters through the sandy soil and undergoes discharge. This water eventually ends up in the bay or the Gulf of Mexico. The proximity of oyster bars in St. George Sound to the island adds to the sensitivity of this situation. In other words, because of its length, position, and unique ecological features, St. George Island is a key to the continued viability of the Apalachicola bay system. Several years ago, a bridge from the mainland was constructed; this added to the prospects of residential development on the island. There has already been a relatively rapid rate of growth although this has occurred without zoning restrictions, sewage treatment facilities (septic tanks are generally used), solid waste disposal, and storm water runoff control. The island is presently in a state of flux with various interests vying for its use.

The major landowner on the island (Leisure Properties, Ltd.) proposed a test area for development of about 800 acres which would be carried out under the developments of regional impact (DRI) guidelines provided under the Florida Environmental Land and Water Management Act of 1972 (Table 3). This law places control of development solidly in the hands of local (county) interests. There are both positive and negative features to this approach. Local control is favored because it allows more immediate feed-back to those who will be most affected by the proposed development. On the other hand, county commissions in Florida rarely have the expertise at their disposal to evaluate the DRI, and consequently must depend on state agencies, regional planning agencies, and local experts for guidance. This can be confusing, especially when there is little scientific data on which to base a far-reaching zoning or subdivision plan. In the case of St. George Island, scientists associated with the Florida Sea Grant Program in Apalachicola Bay have worked with county and state agencies, and the developers to provide a plan for the long-term management of St. George Island. Included in

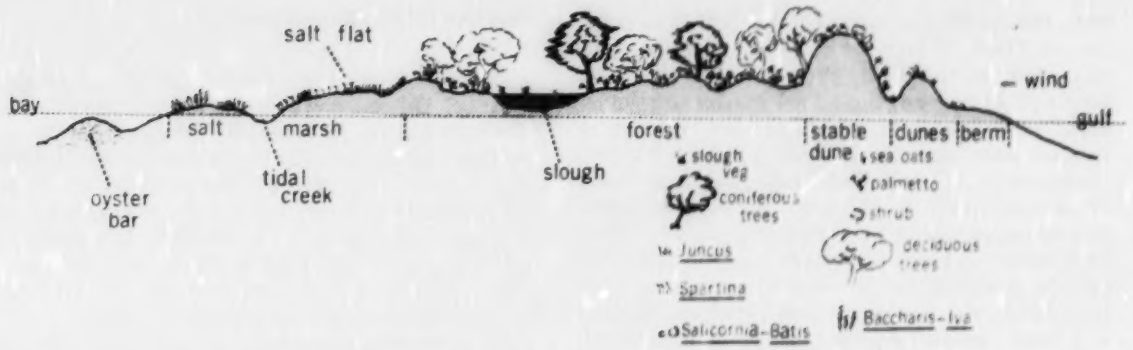


FIGURE 9.—Idealized cross section of a barrier island with special application to St. George Island (modified from Clark, 1974).

this plan would be the provision of an advanced sewage treatment plant, storm water runoff and nutrient control, a regulated pest control program, protection of sensitive portions of the island-bay system, and so forth (Livingston, 1974). A baseline study would precede any development and would continue throughout the various phases. Any impact determined by the scientific studies would be reported to state and county officials and the source of the problem would be eliminated before development could proceed. The DRI would make this a legal necessity. Funds for such studies would be provided by the developer and administrated by the county commission to avoid conflicts of interest. Such a plan is not without liability. It is possible that chronic pollution such as heavy metal contamination could escape detection and build up to levels that would eventually have an impact on the bay ecosystem. Another possibility is that increased development would lead to other forms of expansion that are not as susceptible to control. Such a program also depends on the economic viability of the developers, which is not always assured.

An alternative to this plan would be a restrictive zoning ordinance that would severely reduce the population on the island. In this case, there still would be no support facilities (sewage plant, storm water control, et cetera), although the population increase would not be as rapid. Whether or not such a plan would work over the long run is also doubtful. Another possibility is the purchase of large portions of the island by private foundations and/or municipal and state agencies. Presently, all these alternatives are being examined by various groups. This is a good example of the difficult types of decisions that must be made in any comprehensive planning program.

The Role of Research and Education in Resource Management

There is a growing realization of the importance of long-term scientific monitoring programs in the management of estuarine systems. Such research should be coordinated with state and local administrative bodies so that such knowledge can be utilized in the planning process. This should involve local interests so that control remains realistic and compatible with user concerns. Such research can be coordinated with educational processes to accelerate this process. For instance, local high school classes have been taken on field trips by Sea Grant researchers in the Apalachicola bay project and undergraduates from Franklin County (enrolled at Florida State University) are presently employed in the research effort (Livingston, 1974). As part of the program, the principal investigator also acts as an advisor to the board of county commissioners and serves as a member of several committees that formulate county and city ordinances to protect the Apalachicola system. The interaction of estuarine scientists and county personnel has also resulted in the generation of county funds for the research effort. Thus, using the federal Sea Grant Program as a base of support, matching funds have been provided by local, private, and municipal interests for baseline studies so that answers can be found to the problems of the bay. The research and educational effort should not be underestimated in any management program, and actually forms the basis for understanding that is fundamental to the success of any planning effort. There should be increased incentives for scientists to interact with local interests and state agencies to apply basic biological research to the problems associated with development in natural drainage areas.

The Future of the Apalachicola System

The Apalachicola drainage system is presently the focal point of development by various interests. On the one hand, it is still in a relatively natural state with Apalachicola Bay providing the basis for extremely productive sport and commercial fisheries. On the other hand, various agricultural, commercial, and industrial interests are beginning to utilize the system in ways that will eventually come into conflict with present usage. The Apalachicola system is actually a microcosm of what is occurring in the estuaries all over the country, with conflicting interests competing for the use of terrestrial and aquatic resources. A number of state and federal agencies, responsible for the administration of a welter of new environmental laws and regulations, are also involved in this situation. There are indications that long range planning and resource management based on extensive scientific data will be necessary if such systems are to remain productive. However, despite a serious promotional buildup by industrial interests and the Army Corps of Engineers to promote damming and industrialization of the Apalachicola River, no move has been made to fund a research program to answer the serious questions concerning the effects of such actions on the aquatic system and those who depend on it. Various approaches have been attempted to promote the planned usage of the Apalachicola drainage system. Land that is considered environmentally sensitive and endangered has been purchased by the State of Florida for preservation while land swaps of upland forested areas for endangered wetlands are presently under consideration. An estuarine management program, funded by the Florida Sea Grant program, has served as a platform for the development of an educational and research program designed to promote an orderly approach to the development of the Apalachicola aquatic system. Various private interests such as pulp mills and land developers have contributed to this effort to determine sensible ways of utilizing the wetlands without having an impact on the bay productivity. Various actions by the State of Florida have aided in this effort. Preservation, conservation, and development areas have been determined, and new laws and regulations have enabled a new approach for planning at the local level. County governments can now utilize various state and federal resources to help them in the effort to plan for future development. When combined with scientific research teams from various disciplines, these interactions can lead to constructive action. In spite of all this, major unresolved problems exist. Non-point sources of pollution and activities relating to an impact on the aquatic energy systems have not been adequately researched. The imminent determination to industrialize the river and develop broad new residential areas on the barrier island system of the bay will demand considerable planning if the Apalachicola Bay system is to remain productive. Increased cooperation and interaction of federal, state, and local agencies will be necessary to develop successful management schemes.

APPLICATIONS AND CONCLUSIONS

1. The successful development of an estuarine resource management plan would depend on a complete environmental resource analysis. This would include baseline scientific data, and comprehensive economic and land inventory information so that decisions can be made concerning resource utilization by conflicting interests.

2. Based on the available information, decisions should be made concerning how the system is to be utilized. This would depend on population distribution, the extent and form of industrialization, importance of sports and commercial fisheries, aesthetic considerations, and so on. Thus, at an early stage of development, the actual functional use of the system should be determined (industrial, sports or commercial fisheries, recreation, et cetera).

3. Following the initial determination of use, critical or sensitive areas in the system should be identified. This would include an assessment of the impact of point and non-point sources of pollution. Equally important should be the protection of the basic energy system of the estuary. Although various forms of pollutants can harm an estuarine ecosystem, it is possible that through improper land use, the sources of energy for such a system are altered. This can ultimately be translated into a decrease in useful productivity. The significant relationship of the estuary with its associated upland drainage system should be determined so that basic productivity at all levels remains intact.

4. Based on a scientific assessment of the entire drainage system, a broad management scheme should be developed whereby critical areas are preserved. This should be done through the purchase of such areas by state and federal agencies; this could be patterned after the Florida Land Conservation Act of 1972 where public funds are used to purchase environmentally endangered land. Other areas that are considered important should come under some form of conservation and management program. This could be approached in various ways such as areas of critical state concern, state and local set-

back ordinances, and restrictive zoning programs. The federal government should promote advisory services on the local level so that various concerned interests are involved at the decisionmaking level. It is not a matter of doing basic or applied research. Significant questions should be asked, and sound scientific data should be used in the development of an overall management scheme.

5. Because of the individual nature of the ecological functions and problems of each estuarine system, no uniform or generalized scheme of resource management is possible. Administrative functions should be regional and interdisciplinary in nature. The regional approach would be based on the extent of the individual drainage system. In addition to representation of the various local interests within the decisionmaking process, an administrative mechanism should be developed for the translation of scientific data into management and planning concepts. Again, the federal government should provide programs that encourage scientists to participate at the local and regional levels so that information is readily available when needed. This would include educational training programs and coordination of resource inventory analysis.

The ultimate goal of a resource management program for any given estuarine system should thus provide a plan that would be based on objective scientific data and would allow the application of intelligent alternatives to a given local or regional situation. Only in this way can the often difficult decisions be made which concern resource use in our estuaries.

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THE RHODE RIVER PROGRAM

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ABSTRACT

An intensive study of the interactions of the Rhode River, a subestuary of Chesapeake Bay, with its watershed and airshed is being conducted at the Chesapeake Bay Center for Environmental Studies. Rainfall is a major source of nitrogen nutrients for the watershed and the estuary. Very little of the nitrogen in the rain falling on the watershed or that applied to cultivated croplands reaches the estuary. Almost all of the phosphorus loading of the estuary is from watershed runoff. Using land use analysis and watershed runoff studies, seasonal area yield loading rates have been calculated from land use categories. Freshwater wet areas are effective traps for nitrogen, phosphorus and mineral suspended matter, while residential areas and cultivated croplands are major non-point sources of these parameters. Neither the upland soils, nor the tidal marsh sediments can be considered long term sinks for phosphorus. Most of the organic matter which fuels the food chains of the estuary is produced by the phytoplankton, rather than upland forests, tidal marshes, or mud flat benthic plants. The phytoplankton productivity peaks in an area of the estuary in which the ratio of nitrogen to phosphorus is between 5 and 20. Net productivity also peaks in this zone.

Thus this estuary, which has no point sources of pollution, is maintained in a eutrophic situation by nitrogen loading from rainfall and distant sources of water pollution in the bay, and from phosphorus loading from residential and agricultural diffuse sources. Where the ratio of these nutrients is maintained within a biologically useful range intensive phytoplankton blooms develop.

INTRODUCTION

The Chesapeake Bay Center for Environmental Studies, established in 1965 by the Smithsonian Institution, is a 2,600-acre research facility on the Rhode River. This subestuary on the western shore of the Chesapeake Bay just south of Annapolis was chosen for a long-term research program because it is small enough (two square miles of open water) to be studied in detail, yet large enough to have the characteristics of an estuary.

Although the estuary is near major research centers, its shoreline had not been completely developed when the Center was established. Portions had been bulkheaded or filled and developed for marinas and suburban housing, but large areas are still relatively undisturbed. The land in the watershed of the river still falls into a mixture of land use categories typical of the western shore of Chesapeake Bay.

The research program at the Center is concerned largely with the interaction of the Rhode River estuary with its watershed and man's impact on this system. The effects of air pollution from the Baltimore-Washington metropolitan area, land use practices, and the disposal of sanitary waste waters generated by a rapidly growing population are being studied. The research program is being conducted by scientists from the Smithsonian Institution, the U.S. Geological Survey, and from nearby universities, principally The Johns Hopkins University and the University of Maryland. The broadly based interdisciplinary effort begun in the mid-1960's, has grown to a major research program during the last four years.

The research at Rhode River has been concerned with (1) gaining an overview of the current status of the estuarine-watershed system, and (2) attempting to dissect the system in order to understand the function and quantitative importance of each component.

The components have been considered from two points of view:

Spatial components.—Airshed and weather, uplands, tidal marshlands and mud flats, open water tidal creeks, the main basin of Rhode River proper, and the spine of Chesapeake Bay.

Functional components.—Physical-chemical conditions (temperature, nutrients, soil or substrate, et cetera), primary producers, primary consumers, secondary consumers, and decomposers.

Each spatial component will have a series of functional components. In the case of tidal marshes, for example, we have asked the following questions: What is the primary productivity per unit of surface area? What organisms carry out this productivity at each season of the year? How much of this pro-

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ductivity is used to support the primary consumer and decomposer components of the marshes, and how much is exported to the Rhode River basin spatial component?

The purpose of this report is to summarize the more important research results of the program, i.e., those relevant to "The National Estuary Study," and to outline research which I anticipate will be carried out at Rhode River in the next few years.

STATEMENT OF PROBLEM AREAS

We lack intensive, long-term measurements of the key parameters on which to base a better understanding of the functional role and significance of each component of an estuarine ecosystem.

We also lack sufficient data processing and data utilization from ongoing estuarine research programs.

As a result of problems above, we do not possess the perspective necessary to see the relationship of each component to the system as a whole. Until we obtain this perspective, efforts towards optimum management of estuaries are certain to be arbitrary and often counterproductive.

REVIEW OF RESEARCH RESULTS FROM RHODE RIVER PROGRAM

Airshed Interactions

Rain falling on the Rhode River and its watershed contributes significant amounts of nutrients, especially nitrogen. A network of rain gauges has been established on the watershed and rainwater is collected routinely in a special receiver for chemical analysis (Correll, 1973).

In the 1973-74 hydrological year rainfall on the Rhode River watershed deposited 0.40 lb of phosphorus per acre year, mostly as free phosphate, the form most biologically available. This is a relatively small amount compared to an average fertilizer application rate of 29.5 lb/acre year on the cultivated crops of the watershed (Correll, 1973). However, the rainfall also deposited 6.6 lbs. of nitrogen per acre year (2.84 lb nitrate-N and 3.79 lb organic plus ammonia-N/acre year). Most of this nitrogen came down in forms readily utilized biologically. The average fertilizer application rate on cultivated crops on the watershed is 57.3 lb N/acre year (Correll, 1973).

The daily rainfall area loading rates for each season are given in Table 1. Of course, it must be remembered that the rainfall loading is applied to the entire watershed and the Rhode River itself, while fertilizer is not.

Table 1.—Nutrient loading rates from rainfall on the Rhode River watershed (1973–74 hydrological year)

Season	Total-N (lb/acre day)	Total-P (lb/acre day)	N/P (wt ratio)
Winter (Dec., Jan., Feb.)	0.0133	0.00049	27.0
Spring (Mar., Apr., May)	0.0277	0.00183	15.1
Summer (June, July, Aug.)	0.021	0.00160	13.0
Fall (Sept., Oct., Nov.)	0.0106	0.00046	23.1
Entire year	0.0182	0.00110	16.6

Upland Interactions

The watershed of the Rhode River is composed of many small drainage basins, some of which drain into discrete creeks that can be monitored by instrumented sampling stations. Five such stations have been in operation for one year. Water discharged from each of the five basins is recorded, and volume-integrated water samples are taken automatically for analysis of sediment and nutrient concentrations. Each of these drainage basins contains a different proportion of five land use types: cultivated cropland; wet areas such as ponds, swamps, and marshes; pasturelands; natural areas such as forest and brushland; and residential areas plus roads and bare areas. The average land use on these watersheds was 23.5 percent cultivated crops, 0.5 percent wet areas, 57.2 percent natural areas, 13.6 percent pasturelands, and 5.2 percent residential, plus others. The total watershed area monitored was 2,100 acres. The data gathered on water discharge and concentrations of sediments and nutrients have been used to determine mathematically the area loading rates delivered from each of the five land use categories to the Rhode River at different times of year. Some of these rates are given in Table 2. Although they are subject to refinement in precision as the project acquires a larger data inventory, these rates are of considerable interest in predicting the effects of land use change upon the turbidity and nutrient loading of an estuary on a seasonal basis. Equivalent data has not yet been processed for the fall season.

The area yields from cultivated cropland are consistently higher than from natural areas for all three parameters. The ratios of area yields for nitrogen to phosphorus for cultivated croplands decreased from 21 in winter to about three in late spring and summer. Wet areas such as swamps and marshes obviously trapped large amounts of all three components per acre and are therefore very important with respect to estuarine pollution. (A negative value in the table indicates the removal of the material from runoff water and shallow groundwater as it flows through land in this category.) In general, loading from

Table 2.—Nonpoint source area loading rates from upland land use categories to the Rhode River estuary

Land use category	Total-N (lbs/acre day)	Total-P (lbs/acre day)	Mineral suspended matter (lbs/acre day)
Winter			
Cultivated cropland	+0.0052	+0.00036	+0.31
Wet areas [a]	−0.095	−0.014	−4.6
Natural areas [b]	+0.00033	+0.00021	+0.088
Grasslands [c]	+0.016	+0.0020	+0.087
Residential and others [d]	−0.0034	−0.0025	+0.44
Spring			
Cultivated cropland	+0.0080	+0.0026	+0.80
Wet areas [a]	−0.38	−0.088	−26
Natural areas [b]	+0.0029	+0.00054	+0.026
Grasslands [c]	−0.0087	−0.0051	+0.41
Residential and others [d]	+0.031	+0.026	+3.3
Summer			
Cultivated cropland	+0.023	+0.0098	+1.4
Wet areas [a]	−0.36	−0.16	−36
Natural areas [b]	+0.00085	+0.00021	−0.050
Grasslands [c]	−0.014	−0.0098	−0.023
Residential and others [d]	+0.014	+0.018	+1.2

[a] Includes open water, freshwater, marshes and swamps.
[b] Includes forest and brushlands.
[c] Includes primarily pastureland.
[d] Others include bare areas, paved areas, dumps, roads.

grasslands tends to shift from high positive values in winter to negative values in summer. In spring and summer, the land categorized residential was a major source of nitrogen and phosphorus.

Residential land was always a major source of mineral suspended particulates. In contrast, natural areas usually had area loading rates of nearly zero for nutrients and low rates for mineral suspended matter. Rainfall area loading rates for nitrogen and phosphorus (Table 1) usually exceeded area loading rates from natural area uplands (Table 2).

Stream samples were taken at times of known water discharge and analyzed for total and fecal coliform bacteria as indicators of potential pollution with human pathogens. Not enough data has been obtained to calculate reliable area yield rates for each land use, but some conclusions seem justified for the watersheds overall. Progressively higher average area discharge rates for coliform bacteria were observed on February 21, March 18, May 13, and June 17, 1974 (1.9×10^3, 4.5×10^3, 4.5×10^4, and 7.7×10^4 total coliforms/acre min, respectively). This was despite the fact that progressively lower water discharge rates were measured for the same time periods. No one watershed had obviously different emission rates.

Radioisotope studies were conducted of the phosphorus cycling and flux occurring in natural woodlands subjected only to rainfall loading or to increased mineral loading designed to simulate land application of sewage effluents (Correll and Miklas, 1974). Phosphorus loading rates of up to 3.8 lb/acre day were used. Neither the leaf litter zone nor the soil column were able to bind and store significantly greater amounts of phosphorus than were present initially. Applied phosphate was rapidly assimilated by microorganisms in the leaf litter zone and then moved into the soil column. Within the soil, the phosphorus, still packaged within microbial cells, moved laterally in the interstitial waters and was lost from the forest as shallow groundwater runoff in the local streams.

Tidal Marshes and Mud Flats

Many of the tidal marshes and mud flats bordering the Rhode River today are located in or adjacent to Muddy Creek, a headwaters tidal channel. These areas function as filters and thereby alter the water quality of the tidal waters. It is estimated that the Muddy Creek system, which drains 66 percent of the watershed, discharges about 16 tons of suspended particulates per year into these mud flats. Most of this load is precipitated as a result of aggregation and reduced water velocities before it passes into the Rhode River proper. Thus the mud flats and tidal marshes act as sediment traps.

The tidal marshes also assimilate phosphorus and nitrogen nutrients at a high rate. These marshes have large surface areas in contact with the tidal waters. These surface areas are covered with periphyton, a community dominated by algae and bacteria. The bacteria in this surface microbial film are responsible for most of the nutrient uptake (Correll, Faust and Severn, 1973; and, Bender and Correll, 1974), following which the nutrients are transferred down or laterally in the interstitial waters of the sediments by the pumping action of the tides until they reemerge in the water draining into the tidal channels at low tide. No significant net accumulation of mineral nutrients occurs under natural or increased mineral nutrient loading in the high or low tidal marshes of the Rhode River (Correll, Faust and Severn, 1973, and, Bender and Correll, 1974), but many organic forms of phosphorus and nitrogen are mineralized in the overall process. Thus, incoming tides contain a higher proportion of organic and particulate forms of mineral nutrients than ebbing tides.

Experiments with periphyton on artificial substrates in the mud flats indicated average phosphorus uptake rates of 0.18 ton P/acre year and an average turnover time for total periphyton phosphorus of 29 hours. The primary production of tidal

marshes and mud flats is due to the activities of submerged and emergent higher plants and the periphyton microbial community on the underwater surfaces.

The productivity of tidal marsh emergent plants (commonly called grasses) is usually considered to be high. In the Rhode River, the productivity of various marsh communities, as estimated from standing crop at the end of the growing season, varied from 1.4 to 5.0 ton dry wt/acre year (Correll, 1973). The most prevalent communities had productions of about 2.6 ton dry wt/acre year. Actual carbon dioxide uptake measurements in high marsh communities gave values which ranged up to 222 lb/acre day as a maximum during the peak of the growth season, but that season only lasts about two months. Thus, these figures are within a factor of 2 of the standing crop values. In the mud flats the productivity of the beds of submerged vascular plants as judged by standing crop in July, was 0.18 to 0.23 ton dry wt/acre year.

The underwater surfaces of both marshes and mud flats are covered with periphyton. Studies of periphyton growth on artificial substrates gave an average rate of 0.18 ton of ash-free dry wt/acre year (Correll, 1973). Actual rates of periphyton net primary production, as determined by radioisotope methods, averaged 1.1 tons ash-free dry wt/acre year (Correll, 1973). Because this value does not account for losses due to grazing, death, et cetera, it is much higher than the biomass growth rate value on artificial substrates. Even so, the productivity of the mud flats (submerged vascular plants plus periphyton) was lower than the productivity of the tidal marshes (about 1.3 vs 2.6 tons dry wt/acre year, respectively). Periphyton carries out primary production in the marshes all year, but the rates within the marshes have not been measured at Rhode River. This primary production has the potential for making two significant contributions to the Rhode River: (1) providing a food supply for spawning and nursery grounds, and (2) providing the estuary with dissolved and particulate organic matter carried by tidal currents.

There is little doubt that the first is a bona fide role for this component of the system. However, experiments at Rhode River tend to deny the importance of the second. Carbon dioxide exchange measurements on one meter square experimental plots in high marsh communities indicate that, due to the metabolism of the microorganisms within the bottom sediments and the surface litter layer, most of the organic material produced in these marshes is respired away again while still in the marsh. Thus, most of the grass productivity actually fuels the food chains of the marsh, rather than being exported by tidal currents to the estuary.

Another question concerning the role of tidal marshes and mud flats is, how effective are they at removal of bacteria carried into this area by the runoff from the Muddy Creek system? Preliminary data suggest that once the bacteria are discharged into tidal waters, most of them survive until they are exchanged into Chesapeake Bay proper.

Rhode River

The chemical and physical properties of the estuary have been studied extensively. Gradients exist for the concentrations of most parameters due to freshwater runoff from Muddy Creek at one end of the estuary and the exchange of brackish water from the bay at the other. These gradients undergo seasonal changes which must be understood if the biological components of the estuary are to be analyzed.

The surface water of the bay adjacent to Rhode River typically reaches a minimum salinity (4–5 percent) in May or June due largely to flushing by the Susquehanna River. It then increases steadily to about 12–13 percent by November or December (Correll, 1973). This cycle controls the rate of exchange of the waters in the lower Rhode River. Local watershed freshwater runoff is usually highest in winter and spring, while it often reaches values of essentially zero in late summer or fall.

The total load of suspended particulates in the estuary varies from about 60 tons in the fall to 300 tons in the spring and summer, of which organic matter comprises an average of about 60 percent (Correll, 1973). The turbidity decreases from upstream to downstream. These particulates are important as sites for microbial attachment and for binding of organic matter and phosphorus compounds. They are also important because they severely limit light penetration and thus primary production.

The nutrients (P, N, organic matter) also decrease toward the mouth of the estuary. An exception is nitrate nitrogen, which in the spring has a minimum concentration in the middle of the river (Table 3, and Correll, 1973). Thus, phosphorus in the estuary derives almost entirely from the watershed and decreases in concentration toward the bay due to exchange-dilution with waters of lower phosphorus content. Phosphorus also is deposited in bottom sediments through sedimentation of particulates during normal conditions when bottom waters are not anaerobic. Massive pulsed releases of phosphorus from bottom sediments occur when bottom

Table 3.—Mineral nutrient concentrations in Rhode River surface waters

	Sta.	Total-P (ug P/l)	Dissolved Ortho-P (ug P/l)	Nitrate + Nitrite (ug N/l)	Org-N + Ammonia (ug N/l)	Weight ratio (N/P)
	April 17 (1973)					
Toward Chesapeake Bay	14	26	3	625	669	49.8
	13	28	6	483	684	41.3
	12	32	3	357	769	35.2
	11	37	3	78	838	24.8
	10	56	2	10	931	16.8
	9	70	2	13	808	11.7
	8	111	43	319	362	6.1
	August 9 (1973)					
	14	187	12	6	1381	7.4
	13	134	10	4	1141	8.5
	12	166	43	6	910	5.5
	11	166	43	5	894	5.4
	10	184	45	2	1011	5.5
	9	195	50	2	1076	5.5
	8	469	126	1	1658	3.5

waters go anaerobic occasionally in the summer. A single such release of about one ton of phosphorus into Rhode River was documented in 1973 (Correll, 1974). The occasional occurrence of transfers of phosphorus from anaerobic, phosphorus-rich deep layers of the bay into Rhode River are also suspected but not well documented. Nitrogen enters the Rhode River from the watershed and airshed in high concentrations most of the year and from the bay in the winter and spring.

Phytoplankton is responsible for most of the primary production in the Rhode River. The plankton blooms usually result from bay phytoplankton being exchanged into Rhode River, where growth conditions are more favorable and their populations increase despite the continuous dilution with bay water. The average net productivity of this phytoplankton in the Rhode River, as determined by radioisotope methods, was about 9 tons dry wt/acre year (Correll, 1973). This value is very high, when compared with 1.3 for mud flats or 2.6 for tidal marshes.

Since very little of the carbon fixed in the marshes is exported to the estuary, and since the surface area of the estuary is greater than that of the mud flats and marshes, most of the organic matter which drives the food chains of the Rhode River is probably also produced in the river. Loading rates for Rhode River for organic matter contained in runoff were estimated to be 25–35 tons dry wt/year on the basis of extrapolation from currently available watershed runoff data. Since the surface area of the Rhode River is 1,236 acres, the average loading rate from watershed runoff is only 0.020–0.028 tons dry wt of organic matter/acre year.

The primary production, supplemented with exogenous organic matter, drives a complex and very productive food chain in the estuary. This food chain has two other components important to the dynamics—primary consumers and decomposers. They assure efficient utilization of the energy stored by the primary producers and the rapid recycling and reuse of mineral nutrients (N and P). Another important component, from man's point of view, is the secondary consumers.

First, let us consider the primary consumers. These consist of filter feeders of all sizes from ciliate protozoans to shellfish. In terms of energy flow and recycling, the most important of these are the smallest, for their metabolic rates, which are related to the ratio of the organism's surface area to its weight, are extremely high. Rhode River supports high populations of ciliate protozoans, rotifers, and shellfish.

Equally important, if high productivity is to be maintained, are the decomposers (predominantly bacteria). A high correlation has been found in Rhode River between phytoplankton populations and bacterial populations. Animals can eat only particulate organic matter, whether bacteria, phytoplankton, detritis, or other animals. They never completely assimilate that food, but release large proportions as dissolved organic matter. This dissolved organic matter can be utilized only by bacteria and thereby made into particulate matter again. Thus, carbon is recycled continuously by the phytoplankton, filter feeders, and bacteria.

Mineral nutrients are also rapidly recycled. In the case of phosphorus, the bacteria are responsible for over 95 percent of the phosphate uptake in Rhode River (Correll, Faust and Severn, 1973). These bacteria are attached to aggregated suspended particulates (Correll, Faust and Severn, 1973). Total phosphate uptake rates in Rhode River average about 1.2 tons of P/acre year. However, since most of this phosphorus is recycled repeatedly, it is not removed from the system at this rate. Apparently all the phosphorus which comes into Rhode River, from a variety of sources, eventually moves on out into Chesapeake Bay proper. This phosphorus movement probably occurs partly as infrequent pulses (Correll, 1974) rather than at a steady rate.

Phosphorus loading of Rhode River from land runoff in tons/year was estimated to be 0.67 from cultivated crops, 0.22 from natural areas, and 1.4 from residential areas. On the other hand, it was estimated that 0.46 tons P/year were trapped in wet areas and 0.36 tons P/year were trapped in grasslands. This phosphorus would otherwise have reached the estuary. The total loading from land runoff was about 1.5 tons of P/year. The direct

Table 4.—Nutrient sources for the Rhode River

Source	Organic matter (tons dry wt/acre/year)	Phosphorus (tons P/year)	Nitrogen (tons N/year)
Uplands	0.020–0.028	(1.5)	(3.7)
Cropland		+0.67	+2.2
'Wet' areas		−0.46	−1.3
'Natural'		+0.22	+0.90
Pasture		−0.36	+0.36
Residential		+1.4	+1.5
Rainfall		+0.25	+4.1
Phytoplankton	9.2		
Mud flats	low	0	0
Tidal marshes	low	0	low
Chesapeake Bay	0	low	high

loading of the estuary from rainfall was about 0.25 tons P/year. Therefore, the total annual phosphorus input to Rhode River is estimated to be on the order of 1.7–1.8 tons. These sources are summarized in Table 4. A pulsed release of one ton need occur only very infrequently to be important. A slow continuous release of phosphorus into Chesapeake Bay also occurs normally due to the exchange of water masses along a phosphorus concentration gradient (Table 3).

Nitrogen loading of Rhode River from land runoff in tons/year was estimated to be 2.2 from cultivated cropland, 0.90 from natural areas, 0.36 from pasturelands, and 1.5 from residential areas. Wet areas are estimated to have removed 1.3 tons of nitrogen, which otherwise would have reached the estuary. Thus, the total loading from land runoff was about 3.7 tons nitrogen/year. The direct loading of the estuary from rainfall was about 4.1 tons of nitrogen/year. These loadings are summarized in Table 4. In addition, some loading occurred in winter and spring through exchanges of water masses from the bay with a higher nitrate content (Table 3). Without this input from the bay, nitrogen loading would have been only 7.8 tons.

Biota require 10 times as much nitrogen as phosphorus for maximum growth, according to generally accepted estimates. The ratio of nitrogen to phosphorus loading in Rhode River, excluding bay exchange, is only about 4.5, indicating a short fall of 9 or 10 tons of nitrogen per year or an excess of about one ton of phosphorus. However, bay water with a high nitrate content contributes the needed nitrogen, and plankton blooms typically peak in the middle of Rhode River where the phosphorus to nitrogen ratio is optimum. The times and locations of this occurrence vary due to a number of factors, including rainfall and the rate of change in the bay's salinity.

In Table 3, nutrient gradient data, which illustrate these principles, are presented for two days. On April 17 a combination of rapid exchange of high nitrate bay water and local watershed runoff had created a nitrate gradient with a minimum at station 10, while total phosphorus showed the normal decrease toward the bay. The weight ratios for nitrogen to phosphorus also increased from upstream to downstream and were well over 10 for most of Rhode River. This resulted in a depletion of the pool of available orthophosphate.

On August 9, the bay water was no longer high in nitrate. Total phosphorus levels had increased in Rhode River (normal for summertime), but were still decreasing toward the bay. Although nitrate levels were now very low, available orthophosphate levels had increased due to lowered demand. Ratios of nitrogen to phosphorus were now less than 10 throughout Rhode River. The presence of a zone with an optimum ratio of nitrogen to phosphorus is at least one explanation for the fact that productivity is currently higher in Rhode River much of the year than in the main spine of Chesapeake Bay.

Is the Rhode River a reasonably closed system, using most of its primary productivity internally to produce primary and secondary consumers, or does it export substantial amounts of primary productivity to the open bay? Several approaches have been followed in answering this interesting question. One utilizes the diurnal change in dissolved oxygen to measure overall community metabolism. An excess of photosynthetic oxygen production over respiratory oxygen consumption would indicate the system produces more than it consumes.

The results for 1973 (Table 5) indicate that section 2 of Rhode River, in which blooms often occur, did produce about 10 percent more than it utilized. The other portions of Rhode River seemed to be a nearly balanced, or closed, system. This data also indicated a net community production for the main portion of the estuary of about 6 tons dry wt/acre year. Since this includes heterotrophic daytime respiration, it is in good agreement with the 9.2 ton estimate of net phytoplankton production.

A second method of examining productivity is to

Table 5.—Rhode River productivity as measured by open-water oxygen metabolism in 1973

	Rhode River segment	Daytime net productivity (tons dry wt/acre year)	Nighttime respiration (tons dry wt/acre year)	Difference available for export (tons dry wt/acre year)
Toward Chesapeake Bay ↑	1	4.43	4.22	+0.21
	2	6.62	6.09	+0.53
	3	6.01	6.33	−0.32
	4	3.65	3.86	−0.21

measure the ratio of net photosynthetic carbon uptake to total community phosphorus uptake. This ratio is called the autotrophy index (atoms inorganic carbon reduced per atom phosphorus assimilated). It should be about 100 for a population consisting entirely of primary producers and 0 for a population consisting of consumers and decomposers only. This ratio had an annual average of 68 for the Rhode River plankton community, compared to an annual average of 25 for mud flat periphyton on artificial substrates (Correll, 1973) indicating a greater proportion of autotrophy in the plankton. Under the conditions prevalent in Rhode River the productivity is normally dominated by nannophytoplankton (algae in the 5 to 10 μm size range) (Correll, 1973). In the summer and fall, however, dense localized dinoflagellate blooms often occur. These organisms are not utilized efficiently as food by filter feeders and are commonly associated with massive fish kills. These blooms are closely correlated with high bacterial populations and high levels of organic phosphorus in the water. The mechanism of the fish kills is not clear. No clear proof of toxins has been demonstrated. Low dissolved oxygen levels in bottom waters at night are also associated with the blooms. The actual causal relationships of these many factors are still not known.

The survival characteristics of coliform bacteria in Rhode River have been studied. In the spring and early summer, when land runoff is occurring, a strong correlation exists between fecal coliform concentrations throughout Rhode River and the factors for dilution of Muddy Creek water by bay water in the various sections of Rhode River ($r = 0.95$ to 1.00). The correlation is much lower for total coliform data ($r = 0.5$ to 0.6). Since Muddy Creek drains most of the watershed, there is a clear indication that the bacteria which give positive fecal coliform assays originate from the watershed at those times. Conversely, many of the bacteria assayed as total coliforms did not originate from the watershed. Survival experiments indicated that high water temperatures and high salinity decreased the survival times of *Escherichia coli* while the presence of suspended Montmorillonite increased their survival.

A search for pathogenic bacteria in Rhode River revealed the presence of fecal *Streptococci* at average levels of 225, 130, and 1,050 per 100 ml of surface water at the mouth, center, and upper end of the river, respectively (Correll, 1973). The numbers present per 10g bottom sediment were usually over 2,400. *Clostridium botulinum* was present in the bottom sediments in three cases out of 24. No *Salmonella* were found. *Vibrio parahaemolyticus*-like organisms were abundant in the water column and sediments except in the winter. These results provide a factual basis for concern over the effects of pathogens on shellfish harvested in Rhode River.

EVALUATION OF PREVIOUS RESEARCH PROGRAM AT RHODE RIVER

The research program at Rhode River has been based on three basic assumptions: (1) An estuarine study must include investigations of the interaction of the aquatic system with its watershed and airshed if the system is to be understood or intelligently managed. Once pollutants have been introduced into the tidal waters, not much can be done. Unless we find the sources and magnitudes of these pollutants we cannot attempt to control them. (2) An estuarine research program must include contributions of information from many scientific disciplines if an overall understanding of the estuary is to emerge. (3) This information must be digested, and the conclusions must be made available to a broad spectrum of people. Otherwise, the problems of managing the estuary will not be alleviated. The scientific community, management people at each level of government, citizens' organizations concerned with the environment, and the general public must have access to these conclusions.

The three programs of the Chesapeake Bay Center for Environmental Studies are responsive to these assumptions. The research program focuses on the Rhode River, its watershed, and its airshed. An information transfer program is underway to relay results of the research to managers and other potential users. The Center's education program is also designed to inform the public about the functioning of the Rhode River ecosystem. In addition, the Center's membership in the Chesapeake Research Consortium helps to insure that its efforts will be coordinated with those of other research facilities concerned with the bay.

So far, I have stressed the positive side of our past effort. We have also encountered many problems. We have accepted the necessity for maintaining an interdisciplinary, interorganizational program in which data is gathered in a well planned, spatially and temporally coincident manner. This has been very difficult to achieve, but we have made progress towards this goal. We also have realized the need to demonstrate the applicability of the findings at Rhode River to other estuaries and their watersheds and airsheds. Some progress has been made in this direction. For example, a one-year study is now underway which compares the Rhode River with the South River, a larger subestuary of the Chesapeake Bay. We have realized the need to test how

much stress different sections of the estuary can absorb without serious deliterious modification. Although some work has been done along these lines, more is needed. Finally, we have encountered severe problems in funding such an ambitious research program. So far, sufficient funds have been found to maintain a viable, but not optimum, program.

Overall, the program has just begun to produce the type of results it was initiated to produce—information which could not have been obtained by individual scientists working alone or in groups on a short-term basis or by studies of only one component of an estuarine ecosystem.

RESULTS WHICH APPLY DIRECTLY TO ESTUARINE MANAGEMENT

Although preliminary, the area loading rates in this report from the airshed and watershed to the Rhode River are available to serve as a powerful tool for management (Tables 1 and 2). They provide an overview of total nutrient and sediment loading on a seasonal basis from rainfall and five types of land use. The effects, with respect to total loadings, of land use changes resulting from development can now be predicted more accurately. The effects on the estuary of a shift from the sewage disposal methods currently used to methods involving application of sewage to land can also be predicted (Correll and Miklas, 1974). On the basis of our research, the use of tidal marshes for spray irrigation of sanitary waste waters does not seem advisable (Bender and Correll, 1974).

The productivity of an estuary has been quantified and compared with the relative amounts of biologically useful energy it receives from land runoff, mud flats, and tidal marshes (Table 4). The role played by nutrients in the very high biological productivity of Rhode River has been outlined (Table 5). Any management decisions concerning nutrient sources or the modification of tidal marshes or mud flats can therefore be discussed in a quantitative manner on a per acre basis with respect to these parameters.

FUTURE TRENDS AND NEEDS IN RESEARCH AT RHODE RIVER

Because of the need to generate data more directly useful to a growing number of scientists and more easily adaptable to systems analysis and model construction, the research at Rhode River will probably become progressively more programmatic. The participants already are becoming thoroughly aware of the complexity of the system and of the limited usefulness of isolated data.

In general, more research is needed on the cycling of nitrogen, the role of toxins in the system, and the dynamics of the primary and secondary consumers.

RECOMMENDATIONS FOR IMPROVEMENT OF THE ESTUARINE ENVIRONMENT

A systems analysis approach to the management of the overall ecosystem is necessary. We need to be able to predict the impact of overall nutrient, sediment, pathogen and toxin loading from all sources upon various sections of and types of estuaries. These waters have to be characterized with respect to their salinity regimens, flushing rates, and depths. The impacts will be calculated in terms of effects upon biological productivity, balance of oxygen production and utilization, presence or absence of noxious species (such as pathogens, dinoflagellates and blue-green algae, jellyfish, and asiatic milfoil). We need to determine the acreage and types of mud flat and tidal marshes which should be preserved as spawning and nursery grounds for fisheries. We need to be able to predict the effect that these areas exert upon estuarine water quality through their function as biological filters. Not until we can do these things can we make intelligent, maximum use of our estuaries.

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ACKNOWLEDGMENTS

The following sources of research data were used in preparing this report (unless otherwise noted, they are employed by the Chesapeake Bay Center for Environmental Studies):

Rainfall and Land Use Maps, Daniel Higman; Fertilizer Practices, David Miller; Suspended Particulates, Dr. Jack Pierce, National Museum of Natural History, Washington, D.C.; Coliform, Total Bacterial and Phytoplankton Populations, Dr. Maria Faust; Marsh Grass Standing Crops and Marsh Community Carbon Dioxide Exchange, Dr. Bert Drake, Smithsonian Radiation Biology Laboratory, Rockville, Md.; Submerged Vascular Plants Standing Crops, Dr. Charles Southwick, The Johns Hopkins University, Baltimore, Md.; Open Water Oxygen Metabolism, Robert Cory, U.S. Geological Survey (stationed at the Chesapeake Bay for Environmental Studies); Pathogenic Bacterial Populations, Dr. Rita Colwell, University of Maryland, College Park, Md. I would like to thank Dr. Eugene Small, University of Maryland, College Park, Md.; Dr. Howard Seliger, The Johns Hopkins University, Baltimore, Md.; and Dr. J. Kevin Sullivan (all members of the Rhode River Scientific Advisory Committee) for their stimulating discussions over the last several years. The detailed data upon which this summary is based can, in general, be found in the literature cited. The research referred to in this report was funded in part by the Smithsonian Institution's Environmental Sciences Program and by a series of grants from the Program For Research Applied To National Needs of the National Science Foundation (administered through the Chesapeake Research Consortium). I would like to thank Mrs. Dorothy Kinsman, Dr. Francis S. L. Williamson, Dr. J. Kevin Sullivan, and Robert Cory for their comments and suggestions on this manuscript. This report was published with the approval of the Secretary of the Smithsonian Institution.

CHARACTERIZATION OF THE NATURAL ESTUARY IN TERMS OF ENERGY FLOW AND POLLUTION IMPACT

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ABSTRACT

An estuary is a complex ecosystem which is subjected to a wide range of environmental fluctuation in "normal" parameters, such as salinity, temperature, and rhythmical tidal action. In today's world more and more estuaries are being assaulted by man-induced factors. Many factors make estuaries an important biological and economic resource, but perhaps the most important of all is the amount of energy in these systems. In order for man to manage this habitat for the greatest benefit to man and the earth's ecosystem, a thorough understanding of the energy budget of estuaries is vital. Society has learned the necessity of "dollar" budget planning; it must now recognize the need and applicability for developing energy budget models of ecosystems for purposes of planning and management decisionmaking.

Attempts have been made to develop these models for a few estuaries, but because of their complexity and relatively high cost, these studies are only in their early developmental stages.

Comparative models must be developed for characteristic types of estuaries to assess their essential common and distinctive features. This will enhance the ability of man to predict the effects of a proposed environmental change in other estuaries without the need for excessively costly environmental impact investigations.

The computer and modeling techniques and the scientific-socio-economic expertise exist to initiate comprehensive studies. What is needed is recognition and continuing support to develop this potentially powerful scientific tool for predictive and management purposes.

INTRODUCTION

Our earth is a dynamic, complex, interacting system of plants and animals living together in a non-living, physical-chemical environment. Like all dynamic systems—whether it be a factory, a city, or a living organism—planet earth needs energy to survive and maintain itself. The basic input of energy is from the sun, and this energy is used by plants to photosynthetically produce organic material (food). This production of organic material forms the primary food source for all life. Thus, a knowledge of how the environment influences both food production and the utilization of food and energy by all living organisms is fundamental to human society.

One geographically small, but extremely important ecological segment of our earth, is the estuary. An estuary is a discrete ecological habitat where sea water rhythmically ebbs and flows within a semi-enclosed coastal body of water. A variable amount of fresh water derived from land drainage enters estuaries; some have relatively little freshwater runoff, while others receive tremendous quantities of fresh water from large river systems. This fresh water may dramatically reduce the salinity of seawater and influence numerous other ecological factors. Hence, the estuary may represent a relatively unstable, dynamic environment.

Great diversity in kinds and shapes of estuaries has been reported in the scientific literature (Lauff, 1967; Odum et al., 1974). However, estuaries typically have certain characteristics in common. Briefly, the principal similarities are: 1) tidal fluctuation, 2) salinity changes, 3) high concentrations of nutrients, and 4) a decrease in numbers of marine species as salinity is decreased. In general, organisms inhabiting estuaries are adapted to live in a dynamic habitat where salinity, temperature, oxygen, and other environmental factors change markedly with time (Remane and Schlieper, 1971; Vernberg and Vernberg, 1972). Although not typical of all estuaries, most have human population centers associated with them. These strategic regions represent an excellent commercial site because they offer a safe harbor for ocean-going ships and a terminal for river traffic as well as being a highly desired recreational area.

Despite the basic similarities common to all

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estuaries, it is necessary to realize that each estuary has its own specific characteristics. These differences between estuaries may be quantitative, such as the amount of freshwater runoff, the amount of wetlands bordering the estuarine waters, and length and width of estuaries. Qualitative differences also exist. For example, some estuaries are bordered by rocky shores, others by salt marshes. Differences in physical-chemical-geological characteristics have a pronounced effect on the kinds and number of organisms living in estuaries. As an illustration, a low salinity estuary will typically have fewer marine species than a high salinity estuary. Since pollutants may affect brackish water organisms differently than marine species, water quality standards and management procedures might be different in these estuaries.

To understand estuaries and to be able to predict the environmental impact of man on these critical regions, similarities and differences must be carefully considered. The view that "if you've studied one estuary you've studied them all" is dangerous scientifically and is unfounded from a management and legislative viewpoint. Pollution control regulations must be based on a sound scientific basis incorporating knowledge of similarities and dissimilarities between estuaries.

ECOSYSTEMS

In recent years, sharp public focus on environmental problems has popularized the long held view of ecologists that the environment is extremely complex and difficult to study on a short-term "crisis-by-crisis" basis. However, rather than being overwhelmed by the complexity of natural ecological systems, ecologists have proposed the somewhat simplified concept of the ecosystem which can be studied by systems analysis techniques and modeling procedures.

Various definitions of an ecosystem exist, but all include the concept that certain plants and animals regularly interact as a unit called a community and that this community exists in an abiotic (non-living) environment. Together the biotic community and the abiotic factors constitute an ecosystem which has a specific characteristic structure (anatomy) and function (physiology). The structural anatomy of an ecosystem is based on such features as the kind and number of species present at different times of the year. In contrast, the functional characteristics include the rate at which the ecosystem functions, such as food production levels and energy flow rates to various ecosystem components.

Our planet is an example of an ecosystem. But, for greater ease of study, this large ecosystem is subdivided into subunits by establishing artificial, but well-defined, boundaries. However, we must remember these subunits interact with each other and do not exist alone. Even by creating these discrete subunits, analysis is still complex, and to be studied properly a multidisciplinary team of scientists and sophisticated computer technology must be involved. Although the general aspects of ecosystems are fairly well understood, the important step of developing refined models for various kinds of ecosystems having predictive and management capabilities is not yet a reality. A generalized scheme of an ecosystem is graphically represented in Figure 1.

The essential feature of an ecosystem is the presence of organisms that are responsible for the production of organic compounds by photosynthetic activity using energy derived from the sun. This process produces most of the food (energy) necessary to support the other biological components of the ecosystem and is called *primary production*. In addition, some bacteria (chemotrophs) can produce complex organic compounds from simple inorganic matter in the absence of sunlight. Herbivores eat primary producers and energy is derived in this manner to sustain the herbivore. In turn, some of this energy is incorporated into organic matter which is available to carnivores who feed on herbivores. The production of organic matter by herbivores is called *secondary production*. In turn, carnivores may be devoured by other carnivores, which represent still another level of organic production and exchange of energy. Parasites extract their required energy from organisms at every level of production. Scavengers feed on food scraps wherever available, while other organisms are responsible for the decomposition of dead biological material. Decomposition products may serve as nutrients for many different types of organisms including primary producers. In estuaries, one of the important food sources is detritus, the debris resulting from the breakdown of biological material which represents potential energy for consumer species. Organisms feeding on detritus are called detritivores.

All of these biological activities take place in a complex non-living environment which has a profound influence on plants and animals. For example, temperature affects most physiological functions. Extremely high or low temperatures may kill an organism, while non-lethal temperatures may influence the rate of photosynthesis or the reproductive cycle. In brief, the ecosystem represents a complex interacting system which is dependent on an external source of energy from the sun and whose functional

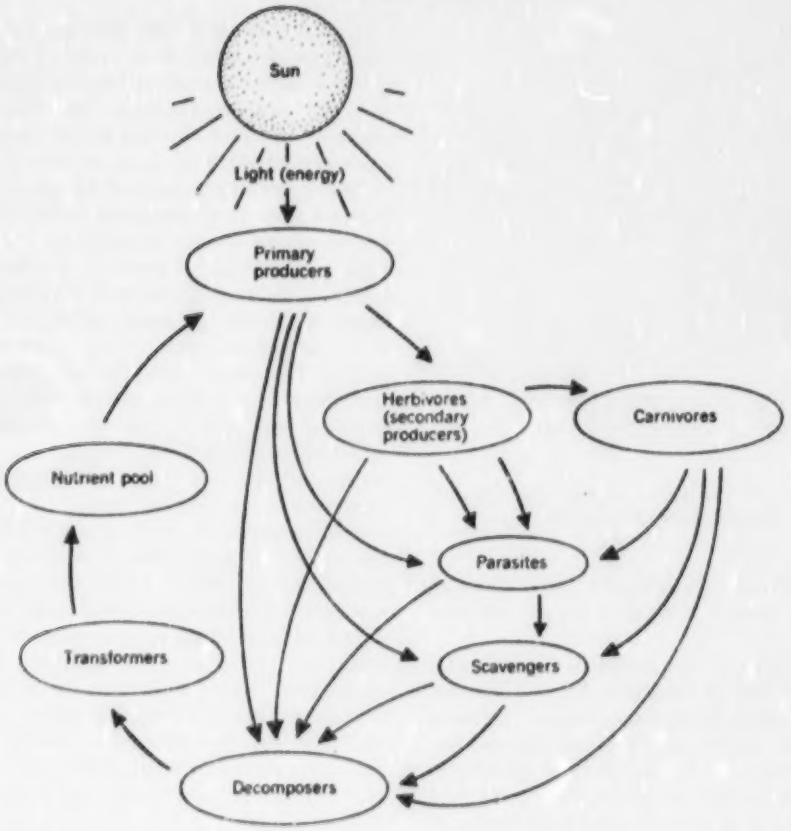

FIGURE 1.—Generalized scheme of an ecosystem. Arrows represent directional flow of nutrients and/or energy (Vernberg and Vernberg, 1970).

activities tend to be cyclic in nature, involving biological, chemical, geological, and physical features.

For an ecosystem to exist and to function, energy is required. An important aspect of studying natural estuarine ecosystems is to determine the input of energy into the system and where and how this energy is transported to and used by the various components of the system. H. T. Odum (1967) has proposed a system of graphically representing the flow of energy by using specific symbols, while other workers use different methods (specific examples presented later). An accounting of the energy within an ecosystem is called an energy budget and reflects input and output of energy from the entire system as well as partitioning of energy within the various components of the ecosystem. Energy may be expressed in various units, such as kilogram-calorie (Kcal), BTU, or grams of carbon, but all are interconvertible.

To analyze complex systems, scientists develop conceptual models which can graphically illustrate the system in simpler terms. Such a model, the "universal" model of ecological energy flow, was suggested by E. P. Odum (1968) (Fig. 2). This model can be used whether analyzing the energetics of an ecosystem or that of an individual organism. Energy flow from one organism to another is represented in Figure 2 by coupling two units of the model. Because of energy loss due to such functions as egestion, respiration, reproduction, and excretion, the first unit is larger than the second. This relationship is of importance and illustrates the obvious fact that the amount of primary production of energy will determine the ultimate size of the ecosystem. Energy input (I) is either assimilated (A) or returned to the environment and not used (NU). Assimilated energy is used for respiration (R) or production (P) of new organic matter. Respiration results in a loss of energy from the system. Production energy may be used for growth (G), stored (S)

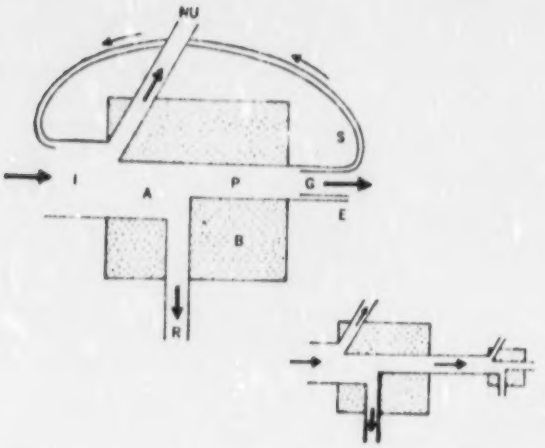

FIGURE 2.—A "universal" model of energy flow through biological systems (from Odum, 1968).

as a reserve for future use, excreted (E) as wastes of metabolism, or energy as used to search out new energy sources.

A basic similarity between economic systems and ecosystems can be readily observed. Economists use some monetary unit, i.e., dollars, francs, or peso, as the source which drives their system, whereas the basic ecosystem unit used by the ecologist is energy. To understand economic systems, the input and distribution of money is analyzed, and the ecologist studies the input and flow of energy through an ecosystem. One obvious difference between the two systems is that an economic system is a manmade entity which depends on a monetary unit which may be changed; in contrast, the energy required to drive an ecosystem is derived from an outside source, the sun, and is not a renewable resource.

Three main types of energy input are important in estuaries: 1) light, 2) organic compounds, and 3) mechanical energy (Odum et al., 1974).

Light energy from the sun is of paramount importance in the production of organic compounds by plant photosynthetic activity (primary production). Phytoplankton (small green plants living in the water), attached large and small algae, and various species of flowering plants living underwater and in marshes and wetlands bordering estuarine waters are the principal primary producers. Not all of the organic matter produced in an estuary is retained; some is exported to adjacent ecosystems.

Organic compounds are introduced into the estuary by rivers, water runoff from adjacent land areas, and from the sea. Some of these compounds provide energy for various groups of organisms. In estuaries associated with human habitation, organic materials resulting from man's activities are frequently added directly to the neighboring estuaries through sewage or industrial discharges. These organic materials represent an energy source for some organisms, but are toxic to others.

The input of mechanical energy may result from various activities associated with winds, tides, and waves. Tidal energy is a principal factor in determining the high degree of productivity of salt marshes. Its turbulence aids in mixing and distributing nutrients. Thermal additives as a result of man's activities, such as heat from thermal nuclear plants, represent still another source of energy.

Energy export from estuaries results from a number of processes such as river flow, tidal circulation, and sedimentation. Water exchange between the ocean and the estuary or between the estuary and freshwater streams may cause a net translocation of organic matter (energy) dissolved or suspended in the water. Energy may flow from the estuarine-wetland ecosystem to the surrounding terrestrial system by terrestrial organisms feeding in the marshes. Man removes energy from estuaries whenever he takes oysters, shrimp, fish, or other organisms. Also, migrating oceanic animals and birds periodically invade estuaries to feed and thus they utilize the estuarine energy reserves. An estuarine energy flow study will analyze the dynamics of where, how, how much, and how fast the energy flows through the estuary-wetlands ecosystem.

In recent years the ecologist has profitably adapted the techniques of systems analysts to the study of ecosystems (Watt, 1966, 1968; Patten, 1971). Rapid strides in computer technology, cybernetics, information theory, and mathematical modeling have permitted a greater arsenal of tools to be available for analyzing complex segments of the earth, such as estuaries. Specific examples will be presented demonstrating attempts to express the functional qualities of estuaries in terms of energy flow models. It should be noted that these studies are in the preliminary, embryonic stage of development as is the entire field of ecosystem analysis. Further, experimental data will be presented which will serve as a basis for predicting the possible impact of environmental manipulation of energy flow in estuaries.

Estuaries are important ecologically and economically because of their naturally high level of energy productivity. For example, estuaries serve as nursery grounds for both migratory oceanic species, such as shrimp, blue crabs, and menhaden, and resident commercially important animals, such as oysters and clams. An important research problem which has

great implications for environmental management is the need to analyze the flow of energy through the estuarine ecosystem. Once known, estuarine energy flow patterns could be manipulated and managed to permit their maximum utilization for man's activities and still prevent the destruction of an estuary as a biologically productive ecosystem. Since man is an integral part of this ecosystem, destruction of ecosystems is not to his ultimate advantage. Energy flow studies have another important function in that energy flow values could be converted into monetary units so that an ecologic-economic basis could exist for making environmental management decisions rather than depending on political or emotional factors.

THE ESTUARINE–MARSHLAND ECOSYSTEM

One of the first attempts to construct an energy flow diagram for an estuarine-marsh ecosystem was that of Teal (1962) involving the marshes of Sapelo Island, Ga. Based on the data of various investigators, Teal proposed the energy flow diagram represented in Figure 3. During a year the input of sun energy is 600,000 kcal/meter^2. This energy was estimated to be partitioned as follows. Most of the energy (93.9 percent) was lost in photosynthetic activity. The gross production was 6.1 percent, and the net production was about 1.4 percent of the incident light energy. Of the energy available to secondary consumers, 55 percent was expended in respiration, while 45 percent of net production was exported to feed estuarine organisms. Since this study was published more detailed energy budgets have been published for various individual species found in the estuarine-marsh ecosystem (Dame, 1972; Hughes, 1970).

Recently a detailed study of a New England salt marsh by Nixon and Oviatt (1973) expanded Teal's work. The two studies differed in that Teal emphasized energy flow in the marsh, while Nixon and Oviatt were concerned principally with energy flow in marsh creeks and embayments. Since consumption for the embayment exceeds production based on a yearly energy budget, this aquatic system must depend on input of energy in the form of organic detritus from marsh grasses. Production values of marsh grass were similar to those from New York, but markedly lower than that of southern marshes. This finding may reflect the substantial difference in climatic conditions between these geographical regions. Marked seasonal differences in energy flow patterns of New England ecosystems were observed and are graphically represented in Figure 4. The flow of energy is much more complex and values are higher during the summer than in the winter. Thus pollutants introduced at different times of the year might not only have a greater differential seasonal effect on northern marshes, but northern marshes might respond differently than those in more southern regions.

To the south, the Newport River estuarine ecosystem is being studied by the Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, Beaufort, N.C. Recently this group reported on the interaction between the major plant producers and the epifaunal and infaunal invertebrates and fish populations comprising the eelgrass community, a part of the estuarine system not discussed by Teal or Nixon and Oviatt. Unlike the system studied by Nixon and Oviatt, there appears to be excess food energy for the consumers. Failure of the herbivores and detritivores to expand to the limits of their food reserves suggests that the organisms may be predator limited, fishes and shore birds being the primary predators (Thayer, Adams and LaCroix, 1975). These authors suggest that the excess plant production in the system is likely exported to the adjoining estuary, thus providing food energy, in the form of detritus, to that system. This ecosystem research program also includes detrital cycles, microbial activity studies, export of materials from grass beds, and trace metal studies.

An ecosystem study of a relatively undisturbed estuary, the North Inlet Estuary, Georgetown, S.C., was initiated by the Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, with support from the Environmental Protection Agency. Also, active studies are continuing in Georgia (Wiegert et al., 1975).

The dynamics of energy flow expressed as carbon in an estuarine-marsh ecosystem, Barataria Bay, La., was described by Day et al. (1973). This study differs from the ones described above in that it deals in greater detail with all parts of the estuarine-marsh complex. Like other marshes, energy was available to be exported to the water, but unlike the findings of Nixon and Oviatt, a net community production in the water column was reported.

In brief summary, although estuarine-marsh energy flow studies are relatively recent, some initial progress has been made in both understanding the dynamics of this fundamental phenomenon and providing information for management decisions.

Since the above studies were done on systems without regard to pollution effect, little information is available on the impact of man-introduced environmental alterations on energy flow per se in an entire estuarine-marsh ecosystem. One example is

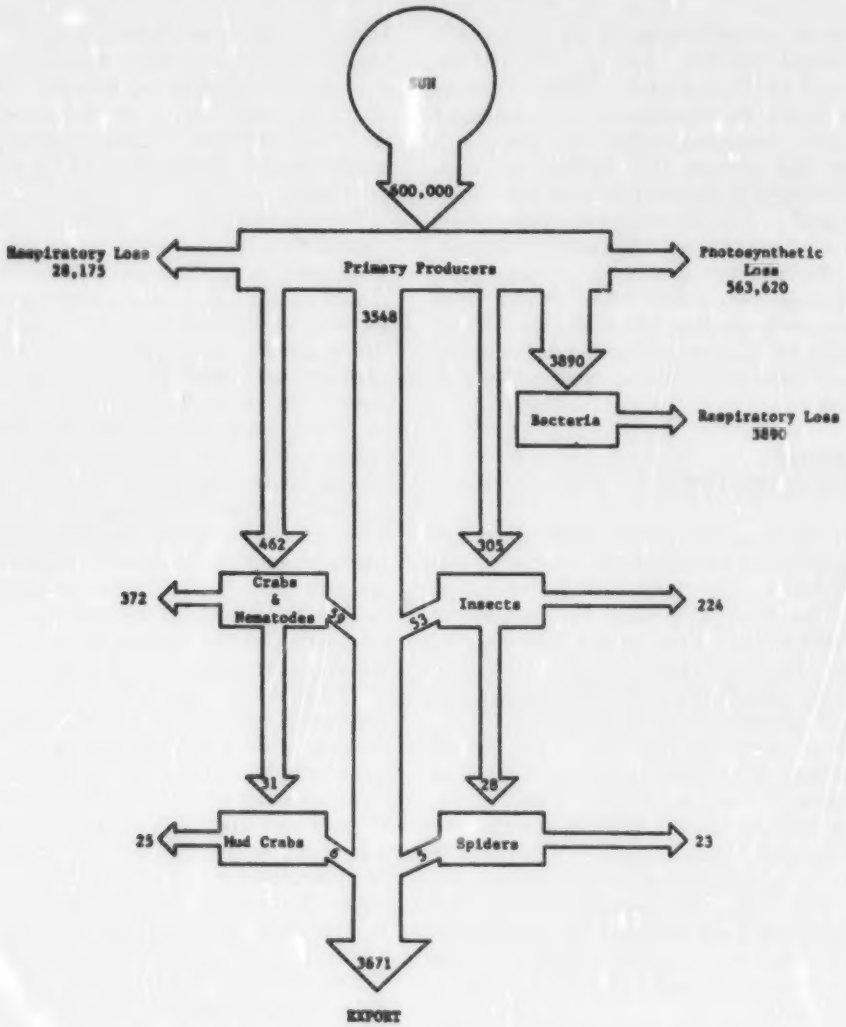

FIGURE 3.—Energy flow diagram for a Georgia salt marsh (modified from Teal, 1962).

given to emphasize how a pollutant (DDT) enters an ecosystem. Woodwell et al. (1976) analyzed DDT residues in estuarine organisms and found both an increased concentration of DDT residues as the size of the animal increased and a greater concentration in higher carnivores than in those at lower food (trophic) levels (Fig. 5). For example, the amount of total residues in plankton was 0.04 ppm while this value was 75 ppm in the ring-billed gull. The gull is at or near the end of the food chain. Although the influence of DDT on energetics was not studied by Woodwell et al., effects of pesticides on the flow of energy are suggested by studies involving single species. DDT will reduce photosynthesis in a primary producer (algae) when few cells are in culture (Wurster, 1968) and reduce the metabolism of the grass shrimp (Sansbury, 1973). These studies suggest that the estuarine energy flow could be adversely influenced by DDT. However, it is not known if the energetics of all organisms in this ecosystem are influenced in the same manner. Hence, generalizations based on a few species are dangerous and probably incorrect.

POLLUTION STUDIES AND ENERGY FLOW

Any environmental factor which influences the physiology of an organism will influence the flow of energy within an ecosystem. Estuaries inherently

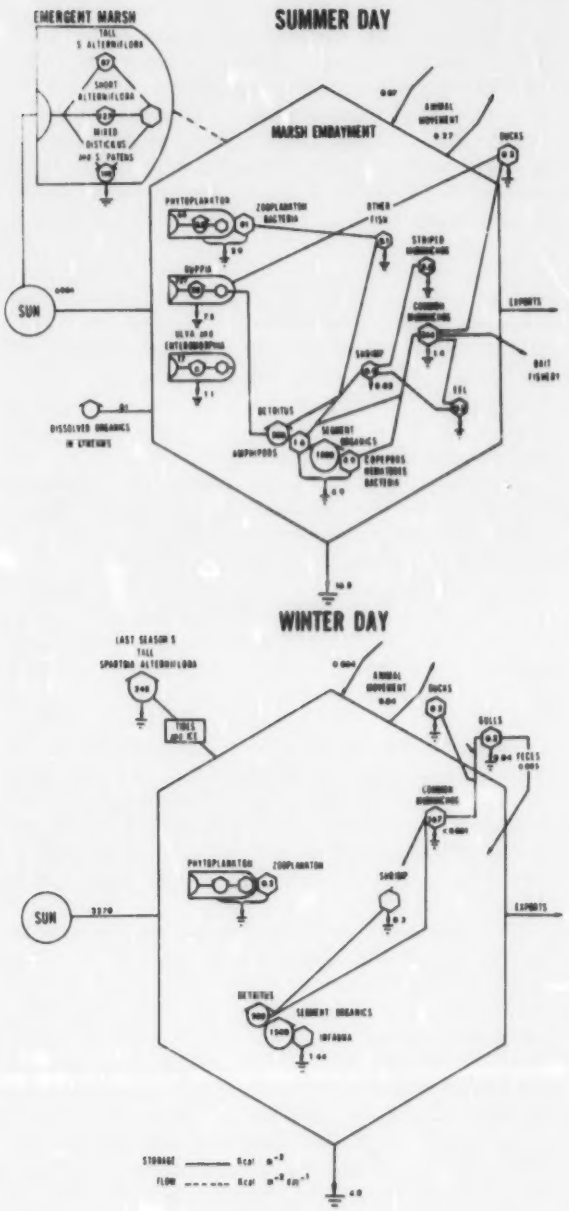

FIGURE 4.—Energy-flow diagrams for composite winter and summer days in the Bissel Cove marsh.

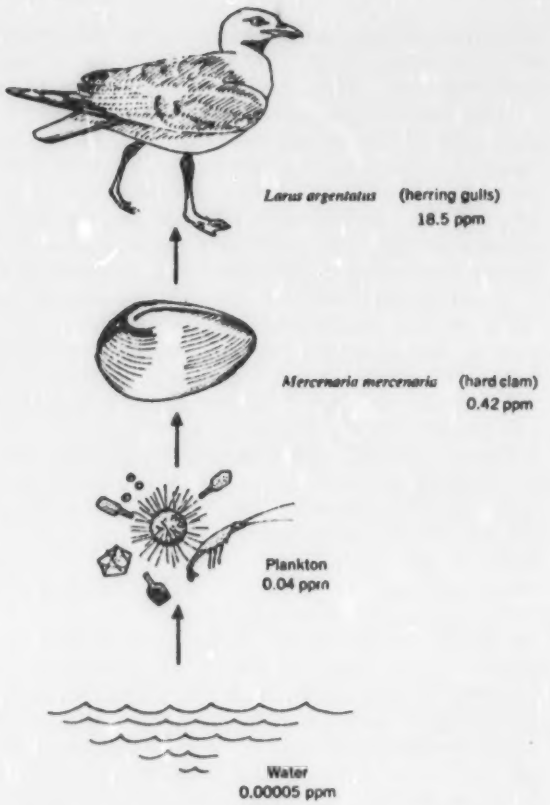

FIGURE 5.—An example of biological magnification of DDT residues (based on data from Woodwell et al., 1967).

are regions where fluctuations in natural environmental parameters occur but also they are regions where man's activities are acutely obvious, such as dredging, thermal discharges, and organic waste disposal. Ketchum (1967) has defined environmental pollution as "any substance added to the environment as a result of man's activities which has a measurable and generally detrimental effect upon the environment." In many instances, a substance has an observable detrimental effect on the biota such as when massive kills of organisms are observed; in other cases a substance might be detrimental to one species but of energetic value to a second one. Therefore, it is difficult to generalize on the influence of a substance (or a factor) on the energetics of an entire ecosystem. This portion of the report will cite the results of a few studies to illustrate how pollutants influence selected segments of the estuarine ecosystem.

Primary production is of prime significance to estuarine energetics since the primary producers are at the base of the food web. In estuaries phytoplankton are the main primary producers in the water, while vascular plants predominate in marshes. It is well known that fluctuation in natural environmental factors will influence the metabolism of phytoplankton, including the photosynthetic activity and the population density. For example, if the light intensity changes, some species will change the amount

of photosynthetic enzymes in their cells while others alter the amounts of pigments (Steeman Nielsen and Jørgensen, 1968). Also, in response to salinity changes the internal osmotic concentration is higher than that of the growth medium. As a result, the range of salinity and the rate at which cell division proceeds depends upon the metabolic rates as affected by altered internal salt concentration (Guillard, 1962). In both of these examples, the energy production of phytoplankton can be altered.

Man-induced changes in estuaries can profoundly influence the phytoplankton and marine angiosperms. Dredging can increase suspended material in the water with the result that light penetration is reduced and the rate of photosynthesis is decreased (Zingmark, 1973). Chemical pollutants can also influence phytoplankton in that sublethal concentrations can inhibit metabolism. Also, since phytoplankton intensifies many substances to thousands of times their concentrations in water, plankton serve to pass pollutants to higher trophic levels when consumed by herbivores. This effect may be more ecologically deleterious than reduced photosynthesis (Walsh, 1972). Differential uptake and sensitivity to copper in species of phytoplankton has been demonstrated (Mandelli, 1969). Although all the species tested were inhibited by copper, some species concentrated copper to a greater degree than others. Copper was more toxic than zinc and mercury in phytoplankton, but the toxicity of the latter two heavy metals was increased when combined in certain compounds used as pesticides (Ware and Roan, 1970). The large plants associated with marshes or living submerged and attached in estuaries are also known to be influenced by pollutants, although specific effects are poorly known. For example, the common marsh grass, *Spartina*, concentrates DDT in its roots, and when the plant dies this toxicant is probably released as part of the detritus based food web (Woodwell et al., 1967).

Environmental problems will arise if nuclear power plants are sited on estuaries. Thermal discharges probably pose the greatest problem, but chlorine, heavy metals, and radionuclides also accompany the waste in the effluent. Phytoplankton cells respond to temperature by changing their rate of cell division (Eppley, 1972). In general, with a 10 degree increase in temperature, the cell division rate increases by a factor of two to three times providing these temperatures are within the range of temperatures favorable to growth. However, elevated temperatures may be lethal or increase productivity depending on the season of the year; growth is adversely affected during summer months but it is stimulated in the late fall and winter (Gurtz and Weiss, 1972). Phytoplankton passing through the condenser coil of a generator plant are faced with thermal stress, mechanical damage by impellers of pumps, and chlorination of the coolant water. Chlorination reduces survival and productivity of all algae, and, if the condenser water temperature exceeds 14.5°C–16°C of the incurrent water, photosynthesis is reduced (see review of Rice and Ferguson, 1975).

Radioactive substances are rapidly concentrated by the phytoplankton and the attached seaweeds and are easily passed on to herbivores. Baptist and Lewis (1969), when measuring the transfer of ^{65}Zn and and ^{51}Cr through a four-step food chain, found radionuclides readily transferred to the highest trophic level, but the levels of concentration generally declined up the food chain.

In addition to primary producers, consumer organisms are also influenced by pollutants. When young oysters, which are filter feeders, consumed zooplankton exposed to a mixture of DDT, toxophene, and parathion, they exhibited a greatly reduced growth rate and a high incidence of pathological changes (Lowe et al., 1971). Another filter feeder, the clam, *Mercenaria mercenaria*, showed abnormal metabolism when exposed to methoxychlor and malathion (Eisler and Weinstein, 1967). Fiddler crabs ate detritus containing DDT for 11 days without any overt damage. But five days later all had lost muscular coordination which for all ecological purposes is a sign of death (Odum et al., 1969). Although carnivores are also influenced by pesticides, sensitivity varies greatly with the species (Butler, 1971).

The effects of organophosphorous compounds in combination with thermal stress are just the opposite to those of the chlorinated hydrocarbons, for survival is increased with decreasing temperature. There also seems to be a wide range of relative toxicity of the two types of pesticides in marine organisms; teleosts are less resistant to chlorinated hydrocarbons than molluscs, and about equal in sensitivity to decapod crustaceans. Crustacea, however, are highly susceptible to organophosphorous compounds; molluscs relatively resistant; and teleosts are intermediate between these two groups (Eisler, 1970).

Heavy metals, such as cadmium and mercury, also influence the survival and energy budgets of estuarine animals. Studies on the fiddler crab will illustrate this point. Mercury caused the respiration rate of adult and larval stages to decrease from the normal depending on temperature and salinity. In contrast, cadmium markedly increased the metabolic rate of larvae. That animals do not respond similarly to different heavy metals is further ob-

served in that mercury is most toxic at low temperature and low salinity while cadmium is most toxic at high temperature and low salinity (Vernberg et al., 1974).

The possibility of oil pollution is ever present. Widespread death of estuarine and marine organisms after oil spills has been well documented in the scientific literature, but the physiological effects of sublethal concentrations of the various oil derivatives are poorly known. However, one study by Anderson et al. (1974) demonstrated that the respiratory response of several estuarine species was different when exposed to several concentrations of oil-water mixtures. These findings suggest that the energy flow patterns of estuarine communities would be differentially disturbed by oil spills or chronic low level leaks.

Various field studies have been conducted involving pollution effects on estuarine communities. Some were done as an aftermath of a serious accident, such as an oil spill, while others were done before and after construction of an industrial factory or power plant. Typically, serious spills cause widespread mortality which would obviously curtail the pattern of energy flow.

Most environmental management plans do not involve consideration of ecosystem energetics. However, one example will demonstrate a preliminary attempt at how management decisions involving an estuarine and coastal ecosystem can be based on energy flow considerations.

Currently a management plan for development and channelization of the Atchafalaya Basin of Louisiana is under study. This plan involves estuaries and wetlands. Young et al. (1974) contributed to this project by using models of energy relationships on a regional and ecosystem basis to consider management alternatives. The plan with the largest energy flow values would be considered to be the greatest contributor to economic vitality.

Estimates of the existing annual energy flow patterns were made and the influence of three different management plans on energy flow was projected. These different plans were grouped as follows: 1) distribution of water and sediments widely filling the present basin and then going further by planned diversions or by accidental overflows; 2) central channelization which would shunt much of the water and sediment directly to an estuary which would result in delta formation and filling in of low wet areas to the south; and 3) a rotation plan of filling one basin, such as the Atchafalaya, until levee costs are high and then shifting to another basin for a period of time.

Their approach pointed out the need for more critical data, but based on available information, a preliminary analysis was proposed. Of the three proposed management plans for this area, the one which would distribute water more widely would be of the greatest energetic value to human society. The principal reason for this conclusion is that man's economy (based on conversion of the ecologist's energy unit to the economist's dollar unit) will be maximized when it fits itself into natural energy systems. Thus purchased fuels will add value rather than using massive expenditures of capital to counteract natural system energies.

SUMMARY

The estuarine-marsh habitat is extremely important to the environmental and economic health of the coastal region and the sea. Man, who is an integral part of this habitat, has dramatically manipulated estuaries without having an extensive scientific basis for his actions and sometimes with serious consequences.

To understand the nature of the estuarine ecosystem and to form a more rational basis for management decisions, ecologists have initiated multidisciplinary studies on the energy flow patterns, for no system can function and be biologically productive without energy. An analysis of the input, distribution, rate of transfer, and output of energy is necessary to develop sound management procedures. Based on this information alternative environmental manipulative procedures can benefit from receiving scientific input rather than relying entirely on emotional, economic and/or political considerations.

Production of food and the influence of pollutants in estuarine and marine waters is interrelated with energy flow studies. For example, an understanding of energy flow patterns is necessary if we are to be able to divert energy into maraculture activities without destroying this fragile coastal zone environment. It is also of vital concern to know the possible effects of pollutants on energy flow, since each level of energy input may be affected differently by any one pollutant.

Energy flow studies in conjunction with other investigations provide a better basis to equate a unit of ecological energy to an economic unit, such as dollars. If this is done realistically, then a clear cost-benefit analysis of a proposed environmental alteration emerges.

This paper discusses the general concepts pertaining to energy flow within an ecosystem and reviews various energy flow models of estuaries. Further, specific studies are cited to illustrate how pollutants

affect various estuarine-marsh organisms and alter energy flow patterns. Certain generalities need re-emphasizing in this summary. Pollutants represent many types of physical, chemical, and biological factors. Each pollutant may differentially influence the energetics of the myriad of plant and animal species associated with the estuary. A pollutant may significantly inhibit the metabolism of an important estuarine species thereby dramatically altering the "normal" energy flow pattern, while other species may be metabolically stimulated or unaffected. Therefore, we are unfortunately in the position of needing to examine the effects of each pollutant on numerous species. If this pollutant inhibits organisms representing a lower trophic level, the amount of energy available to the remaining organisms will be greatly curtailed, resulting in a low level of productivity.

It is conceivable that if energetic pathways were better understood, it would be possible to control the level and type of productivity by using selective pollutants to block certain pathways. It is also possible to divert energy along a different pathway leading to increased productivity of ecosystem segments that man wants to manage. This application of energy flow mechanisms could aid in aquaculture practices or hastening the ecological recovery of environmentally disturbed ecosystems.

We need to develop better predictive capabilities to assess the potential effect of any environmental additives not only on important species, but also on the complete ecosystem. Two approaches are recommended:

1) Comparative studies on energy flow patterns in disturbed and relatively undisturbed estuarine ecosystems. An intensive research program dealing with this subject has been started and should continue to be funded. The goal of this research would be to develop the predictive capability, based on studies of various estuarine types, to assist in environmental management decisions.

2) Microecosystem systems—the goal of this research approach is to develop the scientific base and technology to create small scale replicas of larger ecosystems so that the effects of manipulative activities can be studied without possibly damaging an entire estuary. This would not only preserve valuable habitats but also would provide a relatively inexpensive experimental approach to assess the possible effects of a number of environmental alternatives.

Ecosystem studies are relatively new to science and results to date suggest that they could conceivably provide valuable tools for management procedures involving estuaries. Continued support is vital to assess and perfect this potentially powerful scientific tool.

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LIVING AND NON-LIVING RESOURCES

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PROBLEMS, ADVANCEMENTS, AND FACTORS CONTROLLING ESTUARINE WILDLIFE MANAGEMENT PROGRAMS

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ABSTRACT

Marshes and estuaries along our coastlines are among the most fertile and valuable land and water areas in North America. These areas provide habitats for some of our most valuable wildlife and fisheries resources, supplying livelihood, recreation, and aesthetic enjoyment for a multitude of people. Wildlife usage of high quality estuarine areas is extensive. Wildlife management is an attempt to rectify past habitat abuses and then, hopefully, to bring about a positive enhancement of the desired wildlife and their habitats. The wide variety of human activities which pollute estuarine wildlife resources is discussed along with recent progress in estuarine wildlife management programs. Finally, future trends and needs in estuarine wildlife management are discussed.

INTRODUCTION

Our estuaries, the zones of interplay between the margins of the sea and the land are environments for a remarkable assemblage of terrestrial and aquatic life. The complex of estuaries includes extensive bays, harbors, sounds, lagoons, and river mouths that are constantly flooded, and adjacent areas such as tidal flats and semi-upland marshes, salt and brackish water flats, marshes, and mangrove swamps which may be flooded only by the highest moon and storm tides. Altogether they form an ecosystem—a complex of different environments both aquatic and terrestrial.

Marshes and estuaries along our coastlines are among the most fertile and valuable land and water areas in North America. These areas provide habitats for wildlife and fisheries resources, supplying livelihood, recreation, and aesthetic enjoyment for a multitude of people. They serve as production areas and nursery grounds for shrimp, oysters, crabs and fish. They provide wintering areas for a major portion of the continental waterfowl resource, and they are extremely valuable for the production of fur animals and many species of game and nongame animals. The following discussion will be concerned primarily with wildlife other than birds. But one thought must be kept always in mind—there is a connecting webbing of interactions between all forms of wildlife occupying the same habitats.

While estuarine areas have always been important, recent years have witnessed growing public attention and deep concern in their behalf. It is a part of the expanding conservation ethic of Americans who want to retain their heritage of natural beauty, scenic values and the environmental qualities that support fish and wildlife resources. This attitude is reflected in many plans and programs for conservation action—and among these, estuaries occupy a prominent position.

WILDLIFE HABITATS IN THE ESTUARINE ZONE

Wildlife usage of high quality estuarine areas is extensive. Waterfowl and shore birds find these areas essential for nesting, resting during migration, wintering, and feeding. A wide variety of other birds make extensive use of estuaries. These include pelicans and cormorants, long-legged wading birds, eagles and ospreys, cranes and rails, gulls and terns, and some passerines. The aquatic furbearers including muskrats, minks, nutrias, beavers and otters are seldom far from wetlands. Raccoons use wetlands heavily although they may range a considerable distance from them. Other wild mammals including deer, opossums, bobcats, foxes, weasels, skunks, and many small mammals use estuarine habitats extensively but are not restricted to them. Of the large sea-going mammals, some, such as the manatee, the dolphin (porpoise), and seals enter estuaries.

None of the frogs, toads, and salamanders is truly marine, although the larvae of a few have been

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found in brackish pools, and adult toads and frogs have been reported in estuaries. Among the reptiles, the alligator is an important member of the estuarine zone. Along the Atlantic and gulf coasts the most typical turtle is probably the diamondback terrapin.

Of the some 130 fish and wildlife species considered by the U.S. Fish and Wildlife as rare and endangered, 10 use an estuarine habitat extensively and most would probably perish without it. These 10 species are the Florida manatee, key deer, great white heron, whooping crane, Eskimo curlew, Ipswich sparrow, dusky seaside sparrow, Cape Sable sparrow, brown pelican, and the alligator.

From the standpoint of wildlife habitats, the estuarine zone may be divided into nine types—three of which are coastal freshwater types and six, coastal saline water types. Following is a description of each of the estuarine types. Table 1 gives the types, brief description, and acreages of estuarine areas along our coasts. Table 2 lists the kinds of wildlife using estuarine habitats reported by wildlife agencies of our coastal states.

Table 1.—Description and acreage of estuarine types in the conterminous United States

Estuarine category and types	Water depth*	Total acres
Coastal fresh areas		
1. Coastal shallow fresh marshes	Up to 6 inches at high tide	2,213,000
2. Coastal deep fresh marshes	Up to 3 feet at high tide	1,631,000
3. Coastal open fresh water	Up to 10 feet; marshy border often present	197,000
Coastal saline areas		
4. Coastal salt flats	May have few inches at high tide	423,000
5. Coastal salt meadows	May have few inches at high tide	956,000
6. Irregularly flooded salt marshes	Few inches at wind tide	698,000
7. Regularly flooded salt marshes	Up to 1 foot at high tide	1,576,000
8. Sounds and bays	Up to 10 feet at high tide	1,114,000
9. Mangrove swamps	Up to 2 feet	523,000

*Refers to average conditions during growing season.

Table 2.—Use of estuarine types by game and fur animals

	Number of states reporting use in estuarine type								
	1	2	3	4	5	6	7	8	9
Small game:									
Gallinules	7	7	6	1	1	1	1	—	—
Grouse, Sage	1	1	—	—	1	—	1	1	—
Mourning dove	1	1	—	2	—	—	—	—	—
Pheasant	7	2	—	—	2	—	1	—	—
Quail, Bobwhite	4	—	—	—	1	—	—	—	—
Rails	12	11	4	5	9	8	10	—	1
Rabbit, Cottontail	9	2	—	—	—	—	—	—	—
Rabbit, Swamp	4	3	—	1	4	3	3	—	—
Snipe	10	5	—	3	4	3	4	3	—
Woodcock	5	1	—	—	—	—	—	—	—
Big game:									
Black-tailed deer	1	1	—	1	2	—	2	2	—
White-tailed deer	6	5	—	1	1	1	2	—	—
Fur animals:									
Beaver	4	4	1	—	1	—	2	1	—
Bobcat	1	1	—	—	—	—	—	—	—
Fox (Red and Gray)	10	5	—	1	8	2	7	1	—
Mink	16	13	9	—	4	4	7	3	—
Muskrat	16	16	11	1	10	5	11	3	—
Nutria	1	1	1	—	—	1	—	—	—
Opossum	4	—	—	—	—	1	—	—	—
Otter	13	12	10	—	5	—	5	1	—
Raccoon	17	12	11	2	11	6	10	5	—
Skunk	4	4	1	1	1	1	1	1	—
Weasel	2	2	—	—	—	—	—	—	—
Alligator	3	3	1	—	1	1	—	—	—

Coastal Fresh Areas

SHALLOW FRESH MARSHES

Soil always waterlogged during the growing season; may be covered at high tide with as much as 6 inches of water.

Located on the landward side of deep marshes along tidal rivers, sounds and deltas.

Vegetation of grasses, sedges, and other plants such as phragmites, giant cutgrass, big cordgrass, maidencane, jointed spikerush, threesquares, sawgrass, cattails, arrowheads, smartweeds, and arrow-arum.

Much used by feeding ducks, geese, and herons; very much by muskrats; some use by nutria, mink, raccoons, woodcock, and snipe.

DEEP FRESH MARSHES

Soil covered at average high tide with 1/2 to 3 feet of water during the growing season.

Located along tidal rivers and bays, mainly on the Atlantic and gulf coasts.

Vegetation made up of such plants as cattails, wild rice, pickerelweed, and spatterdock; pondweeds and other submerged plants, and surface mats of water hyacinth, alligatorweed, and waterlettuce prominent in openings.

Much used in fall and winter by feeding geese, ducks, sora rails, and herons; and by fish, alligators, turtles, and bullfrogs; some use by muskrats, mink, and raccoons.

OPEN FRESH WATER

Water of variable depth.

Located in tidal rivers and sounds.

Vegetation (mainly at depths under 6 feet, but scarce or absent in stained or turbid waters) of such submerged plants as sago pondweed, redheadgrass, naiads, wildcelery, coontail, watermilfoils, and muskgrasses. In many localities along the gulf, water hyacinth forms mats on the water surface.

Much used by feeding ducks and geese and other water birds; and by fish, turtles, and bullfrogs.

Coastal Saline Areas

SALT FLATS

Soil almost always waterlogged during the growing season; sites varying from those submerged only by occasional wind tides to others that are covered fairly regularly with a few inches of water at high tide.

Located on the landward side of, or as islands or basins within, salt meadows and salt marshes.

Vegetation (often sparse or patchy) mainly of glassworts, seablite, saltgrass, Gulf cordgrass, saltflatgrass, saltwort, and seaside heliotrope.

Rarely used except when flooded, then used extensively by feeding ducks, geese, and shorebirds.

SALT MEADOWS

Soil always waterlogged during the growing season; rarely covered with tidewater.

Located on the landward side of salt marshes or bordering open water.

Vegetation mainly of saltmeadow cordgrass, saltgrass, and fimbristylis; and in fresher parts, Olney three-square and saltmarsh fleabane.

Used a little by various mammals and birds, including geese.

IRREGULARLY FLOODED SALT MARSHES

Soil covered by wind tides at irregular intervals during the growing season.

Located along the shores of nearly enclosed bays, sounds, and rivers, and along open water on the eastern side of the Gulf.

Vegetation mainly of needlerush, saltmarsh bulrush, dwarf spikerush, gulf spikerush, coast waterhyssop, and dogtooth-grass; often with widgeongrass in ponds.

Used very little ordinarily; but where broken by ponds and creeks, sometimes used moderately by feeding ducks and nesting clapper rails.

REGULARLY FLOODED SALT MARSHES

Soil covered at average high tide with 1/2 foot or more of water during the growing season.

Located along the open ocean in eastern Virginia, southern South Carolina, Georgia, and eastern Louisiana, and mostly along sounds elsewhere.

Vegetation mainly of saltmarsh cordgrass. Open water in the marsh may support widgeongrass or sago pondweed.

Used very much by feeding ducks and geese, especially where vegetation-filled ponds are present; much used by nesting clapper rails and laughing gulls; also by feeding herons, mussels, snails, and fiddler crabs; some use by fish and shorebirds.

SOUNDS AND BAYS

Water of variable depth. Portions that are considered shallow enough to be diked and filled.

Located in saltwater rivers, sounds, and bays and, to some extent on the open ocean front.

Vegetation (mainly at depths less than 6 feet) of such plants as eelgrass (North Carolina northward), widgeongrass, sago pondweed, muskgrasses, shoalgrass, manateegrass, and turtlegrass.

Much used by oysters, clams, mussels, shrimp, blue crab, fish and diamondback terrapins; and by feeding ducks, geese, and some other birds.

MANGROVE SWAMPS

Soil covered at average high tide with 1/2 to 2 feet of water during the year-round growing season.

Located along the coast of the southern half of Florida, but best developed on the west coast from Cape Sable to Everglades City.

Vegetation chiefly of red mangrove with some black and white mangrove.

Used much by shellfish, fish, raccoons, and feeding water birds.

PAST AND CURRENT WILDLIFE MANAGEMENT PROBLEMS

Our estuaries have always been areas undergoing changes—sometimes rapidly and sometimes slowly and subtly. All these changes, whether occurring naturally or caused by human activities, affect estuarine wildlife habitats. Those changes which affect wildlife negatively may be termed pollutants in that they contaminate or abuse wildlife habitats. Essentially, wildlife management is an attempt to rectify past abuses of the habitats and then, hope-

fully, to bring about a positive enhancement of the desired wildlife and their habitats.

Most wildlife species discussed in this section occupy positions high on the food chains of estuarine life. Most pollutants which indirectly affect wildlife species by directly affecting groups of organisms lower on the food chains (plankton, shrimp, crabs, fish, et cetera) have been discussed in previous sections. Therefore, those pollutants will only be mentioned here, while problems directly associated with the welfare of wildlife and their habitats will be discussed in greater detail.

Natural Pollutants

Naturally occurring changes in estuarine areas include coastal area land subsidence, floods, droughts, fires, and hurricanes and other high-intensity storms. These changes may be good or bad from the standpoint of their effects on wildlife habitats. The timing of these events, and the plant and animal successional stages of the estuarine areas affected, largely determine whether the changes will be good, detrimental, or even disastrous.

The effects of the timing of natural events on estuarine wildlife habitats and populations are so complex that space limitations here will not permit an adequate discussion. It is usually not a single environmental factor which governs the physiological responses and population dynamics in an estuary, but a combination of numerous factors counteracting, supporting, and modifying each other's physiological effects. The effects of some natural changes [illegible] this report.

It must be kept in mind that many changes in estuarine areas are caused by both natural and human activities taking place far from the estuaries, that is, on estuarine watersheds. The variables of size, climate, geology, and vegetation of these watersheds constitute an important, sometimes critical, array of remote estuarine factors. They determine the volume and chemical nature of fresh water, the kinds and particle-size distribution of suspended sediments, the quality and quantity of organic matter and living organisms discharged into the estuaries, and the seasonal abundance of these properties.

Pollution from Human Activities

An ever increasing range of human activities has, is, and will affect the wildlife resources of our estuarine areas. All concerned and knowledgeable citizens realize that our estuaries are areas of multiple values and multiple uses. So it is that human activities to increase certain values and uses may destroy or at least decrease other values and uses. Our history shows that wildlife values have usually decreased markedly as a result of most of our engineering and industrial activities. Until rather recently, wildlife values received little more than lip service when new activities were being planned for estuarine areas. It is encouraging to note that now many activities are required by various federal, state, and local laws to consider wildlife resources before the necessary permits are issued. It is also encouraging that many human activities that damage or destroy wildlife resources may, with proper planning and timing, work toward the betterment of our valuable estuarine wildlife habitats.

The following brief discussion shows how a variety of human activities has polluted our estuarine wildlife resources.

Dredging: Dredging is a frequent and widespread activity in the estuarine areas. It involves the cutting of new channels, the removal of accumulated sediments from existing natural or artificial channels and harbors, and the removal of material for beach nourishment or other special purposes. Dredging has also been used to create upland flood release channels and to provide marsh drainage for mosquito control purposes.

The principal ecological effects of dredging in coastal waters are:

1. Removal of the original interface between the [illegible] and the bottom, which is frequently an area of high biological activity.
2. Creation of new deepwater areas which may affect, either positively or negatively, animal and plant populations.
3. Increased upstream intrusion of salt water and the chemical, physical, and biological conditions coincident with it.
4. Release of sediments, and of dissolved or absorbed chemicals, into the water.

The effects of dredging in estuarine areas can and have been insidious. Dredging, although local as to each operation, can become general as one poorly planned operation after another changes completely the face of an estuary. Compounding the situation is the problem of alternatives. Inland there are more sites for each land use than is typical for estuaries, and choices are more abundant. In estuaries the alternatives are fewer. Even today, after years of concern, we find that estuaries have little protection from physical destruction. This physical destruction

of estuarine wildlife habitats by dredging and other activities has significantly decreased our environmental heritage.

In summary, estuarine dredging always affects wildlife habitats. The ecological effects may vary from ephemeral and insignificant to permanent and extremely important.

Dredging and filling go hand-in-hand. Dredging creates a need to dispose of spoil, and filling demands areas to be dredged. These activities are carried out in a variety of forms for a variety of purposes.

Filling: Channel dredging necessarily creates spoil which must be disposed of. The three placement methods generally in use (hopper dredges, pipelines to distant sites, and spoil banks paralleling the channel) have different ecological effects.

Where hopper dredges are used to carry spoil to dumping sites, the areas affected (by increasing local turbidity, smothering bottom organisms, and decreasing depth in the dumping areas) are usually so small in proportion to the total area available, that the ecological damage may be trivial unless toxic chemicals are involved. Continued use of such spoil area may, however, change the morphology and biological value of the area.

Pipeline disposal in marsh or shallow bay areas away from the channel may replace food-producing areas or nursery areas with dry land which is of little or no use to aquatic life, however desirable it may be for human habitation or industrial sites. Marshes are a main source of food for estuarine animals, and most important fishes and crustaceans of coastal waters must have shallow-water "nursery areas", preferably vegetated, in which to feed and hide from predators.

Spoil banks bordering the channel on one or both sides may have far-reaching effects on estuarine ecology. The most obvious effect is covering up any bottom plants and animals that live in the immediate vicinity of the channel. The economic loss may be considerable if valuable shellfish beds are involved. These effects are local and do not usually affect a large proportion of the estuary. Also they may be counterbalanced by beneficial effects, such as providing new areas for wildlife (where spoil banks are above tide level). However, more subtle results may seriously disrupt entire bays, especially the shallow estuaries and lagoons of the gulf coast. The depth of these bays depends on wave action and currents caused by wind. A line of spoil bands through the middle of a bay has the effect of cutting the large bay into two smaller bays, as far as wind fetch and water circulation are concerned. The end result is increased silting and shallowing of the entire bay, which increases water temperature and evaporation, and thus affects all life in the bay, for the most part adversely.

Levees and spillways: Construction of levees, especially along the lower reaches of rivers flowing to the seas, has a great influence upon the adjacent estuarine environments. The direction, period, and extent of freshwater flows are modified and changed and so are the patterns of sediment deposition along the coast.

The best example of the effects of levees in America is the Mississippi River, which has been leveed increasingly since 1717 for flood control to improve navigation. The hydraulic, geological, and engineering aspects of this development have been treated in hundreds of reports and papers, but only a few people have given attention to its vast biological impacts.

Fresh water and sediment have been shunted directly to the main mouth of the river and not spread out over a wide delta through several distributaries. As a result, Louisiana is now losing an estimated 16 square miles of coast land a year, most of it being marshland. Bays cut off from the river sediment are deepening, and becoming saltier, with vast local changes in biota.

The flood plain of the Mississippi River covers some 35,000 square miles and about half of this has been cut off from the river by levees, with great changes which in general are damaging to wetlands and wildlife. These changes and the general canalization of the river have also had various effects on the estuarine area of the lower flood plain, most of them apparently harmful to wildlife.

In any case, the whole question of the handling and control of the Mississippi River and other problem river systems must be reexamined in the light of the increasingly recognizable need for the conservation of wildlife and natural environment. Understanding the effects involved would assist in the management of riverine and estuarine environments such as the lower Sacramento and San Francisco Bay.

Municipal and industrial wastes: Many of the estuarine areas of the United States receive discharges of municipal and industrial wastes. The effects of these waste loads on the receiving watercourses depend not only on the characteristics of the waste discharge themselves but also on the nature of the receiving water bodies.

The south Atlantic and gulf coast regions of the United States are in a period of rapid industrial expansion and concomitant population growth. At present the development of these areas has not

reached the magnitude of the megalopolis of the Northeast and population and industry are concentrated in generally scattered areas along these coasts. Within these areas are a wide variety of industrial operations: pulp and paper mills, oil refineries, food processing plants, chemical manufacturing plants, fertilizer plants, power generating plants, and mining operations, to name a few. Wastes from each of these operations have their own peculiar characteristics, and each can have a profound effect on the estuarine environment.

The estuaries along the south Atlantic and gulf coasts have inherent characteristics which differ from those of the north Atlantic and Pacific coasts and which play a large part in determining the effects of pollution on these waters and the means which can be used to dispose of wastes from cities and industries on their shores.

On the Pacific coast the continental shelf is very narrow, deep water and strong coastal currents come close inshore, and waste disposal practice has included the use of ocean outfalls as a common technique.

On the north Atlantic coast the estuaries generally have steep sides and good exchange of water between the estuaries and the open sea. Waste disposal practices in these areas have, in most cases, taken advantage of these good flushing characteristics and count on residual pollutants being rapidly carried away.

The estuaries of the south Atlantic and gulf coasts, on the other hand, have neither of these natural advantages. The continental shelf and shallow water extend for several tens of miles out from the coast, making ocean outfall waste disposal a very expensive proposition. The estuaries themselves are almost all associated with extensive marshlands which serve as a trap for residual pollutants and negate any good flushing characteristics the main stream of an estuary may have. These coasts also abound in the offshore bar-built estuaries that are characterized by very poor flushing properties, small tidal ranges, and shallow depths which, in these latitudes, tend to result in elevated natural temperature. Prevention of water quality degradation from waste discharges in the south Atlantic and gulf coast estuaries must, therefore, depend almost entirely on removal of pollutants at the source of waste disposal rather than dispersion and flushing of partially treated wastes.

Pesticides: An infinite number of poisons are dumped into our streams or washed in from the land and ultimately into our estuaries and the ocean. The number of chemical combinations is almost unlimited. Agricultural and industrial wastes are legion and widespread, and their numbers grow faster than do our studies to learn of their effects. Our agricultural chemicals, known as pesticides, are more appropriately listed as biocides. Many of these are highly stable and some of them are among the most poisonous substances known. When many of these get into our streams they are persistent and have caused serious loss of fish and their food chains. Some are synergistic in their effects and many are highly accumulative. There are examples of low level applications of reportedly harmless chlorinated hydrocarbon pesticides building up and concentrating in fish and wildlife more than a hundred-thousand fold.

The effects of pesticides on estuarine wildlife are primarily effects on lower-level wildlife food organisms. These are discussed in previous reports. We are only now gathering enough information on wildlife species far up the food chains, such as many fish-eating birds and mammals such as porpoises and seals, to show that relatively large amounts of pesticides are being accumulated by these species in our estuaries. Many estuarine wildlife biologists feel that pesticides are causing significant changes in estuaries that are only moderately polluted. However, the interaction of the many physical and biological factors makes the net effect unpredictable at this time.

Dams: Dams on rivers have a number of biological effects on estuarine biota. For wildlife species, the major effect is caused by the resulting change in the regime of freshwater flow into the estuary. A dam built on a river, even far upstream, prevents or delays a large portion of flood waters from reaching the estuary. This causes an increase in salt-tolerant species and a decrease in species that require low salinity either because of physiological need or because they need low salinity to protect them from their enemies (competing species, predators, or parasites). In such a river-estuary system, even reduction of the flooding that normally occurs annually or every few years may radically change the ecology of the estuary, either beneficially or harmfully. Each river-estuary system must be considered independently in relation to the effects on desired wildlife species. An evaluation of the effects of a specific dam on estuarine and marine life requires information on the physical effects, especially on salinity, turbidity, and sedimentation in the estuary.

Other: Many other human activities taking place in estuaries and their watersheds cause pollution in

varying degrees. Activities such as oil exploration and drilling, clear-cutting of large forested areas on estuarine watersheds, water diversions, weed control, hurricane barriers, and the whole gamut of construction activities. Many of these activities cause only temporary and localized pollution and the affected wildlife resources recover quickly. But some, such as water diversions and hurricane barriers cause changes which are long-lasting.

RECENT PROGRESS IN ESTUARINE WILDLIFE MANAGEMENT

Wildlife management is, to a great extent, habitat management. In order to manage habitat, some form of control must be acquired—either direct ownership or some lesser form such as a long-term lease.

The Federal Wildlife Refuge System in the United States began in 1903 with the establishment of the Pelican Island Refuge in Florida by executive order of President Theodore Roosevelt to protect a colony of brown pelicans and other colonial nesting birds. Since then the Federal Wildlife Refuge System has grown to include some 45 refuges which contain significant estuarine wildlife areas. The total estuarine acreage in this system is approximately 700,000 acres.

The objective of our National Wildlife Refuge System is to preserve and manage wildlife and its associated environment for the continued enjoyment and social enrichment of the American people. The attainment of this goal requires that lands, waters, and other natural resources of the system be managed, rehabilitated, and developed for multiple uses and purposes. Basic goals of coastal and estuarine national wildlife refuges, all integrated with national objectives, are: (1) maintenance of adequate populations of migratory birds—rare, endangered, and unique species, and other wildlife through (2) manipulation and preservation of land and water resources, for (3) public use and enjoyment.

In 1937, the Congress enacted the Federal Aid in Wildlife Restoration Act (Pittman-Robertson Act), which provides financial help and has enabled many states to finance significant wildlife restoration work. Under this Act, the 11 percent federal excise tax on the manufacturers' price of sporting arms and ammunition is apportioned to state fish and game departments. A number of states have used these funds to acquire and manage estuarine areas.

With few exceptions, governments below the level of states are not purposely preserving estuarine habitats. Jamaica Bay, 12,000 acres of shallow-water marsh and small islands, is on the doorstep of metropolitan New York. It furnishes valuable habitat for many kinds of wildlife, and is operated by the New York City Parks Department. Some towns and cities along the coasts of Florida and North Carolina have considerable acreages of estuarine areas that are valuable wildlife habitats.

It does not appear feasible to put into public ownership all the estuarine areas necessary for producing and maintaining adequate wildlife populations, nor to supervise all the aesthetic, scientific, and economic uses of estuaries. Publicly owned estuarine wildlife habitats must be supplemented by areas owned by private groups, individuals, and foundations. The National Audubon Society owns or leases a number of estuarine areas. These range in size from 20-acre islands to a 27,000-acre brackish marsh. The Society tries to acquire only those areas containing rare and endangered species of plants or animals or strategic wildlife breeding areas. The Nature Conservancy is a nonprofit organization which buys natural areas, including estuaries. Entirely supported by donations, it obtains natural areas as gifts, by purchase, and by assisting with the purchase. Proving to be a valuable tool in the preservation of natural areas, the Conservancy can sometimes purchase areas quietly and hold them until a governmental agency can obtain appropriations. Private hunting clubs own and manage a number of large estuarine areas. Although most of these areas are managed for waterfowl, other estuarine wildlife also benefit. An increasing number of private owners of estuarine areas are managing their holdings with greater priority given to wildlife resources.

Once control of an estuarine wildlife area is acquired, either by purchase, lease, or other agreements, decisions governing wildlife management are necessary. The conservation agencies may decide to hold them as "estuarine banks" and manage them only when the need has been demonstrated. However, few delay initiation of wildlife management practices. Historically, and at present, the number of estuarine wildlife habitats has drastically decreased. Therefore, the need to manage them is becoming more urgent in order to maintain or expand the production of estuarine wildlife. Also, without active management, estuarine areas often cannot be maintained in the same ecological conditions as when they were acquired.

Nearly all estuarine wildlife areas are maturing and changing in character and to maintain the wildlife values, the long-term problem is to arrest development or set back vegetative succession. Management may also be necessary to restore habitats which have deteriorated through drainage, filling, or other pollutions. Management of an estuarine habitat for wildlife is aimed at increasing the production of resident species or encouraging its use

by migratory species. This can be accomplished by increasing food production, making food more available, and creating a desirable ratio of open water and marsh. The objectives will determine whether an area is to be managed for maximum muskrat production, maximum waterfowl production, or some combination of these and other objectives. Management may also be needed when conflicting demands arise regarding use of estuaries: fishing, bird watching, swimming, waterfowl production or hunting, furbearer production, preservation of rare wildlife species, or other uses. Management techniques are improving and for specific objectives in specific estuarine areas, such as producing moist-soil food plants, rather detailed management information is available. However, space limitations here decree that the subject of wildlife management techniques will be treated only in general terms.

Most wildlife ecologists will agree on at least one important point—that wildlife is a product of the land. The abundance and well-being of most animal populations is an indication of the land's productivity, misuse, or both. It is necessary for the wildlife manager to know well those aspects of the environment exerting the most influence on wildlife populations. Generally, vegetation and soils are the interacting components which must be comprehended to produce the best understanding of wildlife populations.

Following is a brief discussion of wildlife management techniques used on estuarine areas. Significant forward strides have been made in recent years in gaining knowledge of the relationships of physical, chemical, and biological factors which have enabled estuarine wildlife managers to improve conditions for desired wildlife species.

Water control: Water-level control is probably the most important technique in the management of estuarine wildlife habitats. Control of water levels may be used to increase or decrease the salinity, to stimulate germination and growth of desirable moist-soil plants, to attract wildlife to an available food supply, to control undesirable plants and other organisms such as mosquitoes and wildlife diseases, to provide a permanent water supply (as in ditches and potholes) for alligators and furbearers during droughts, to enable trappers and hunters to move about the areas more easily, to clear up turbidity, to recycle nutrients, and for a variety of other purposes. Unwise manipulation of water can pose problems for wildlife. Wildlife habitat in the past was often temporarily destroyed by water drawdown; obtaining enough water for re-flooding at the proper time was difficult, and overcrowding favored the spread of disease. Fortunately, estuarine wildlife research and management have progressed to the point where such mismanagement is infrequent as managers now have broader knowledge of physical and biological characteristics of individual marshes. Bottom topography, soil characteristics, existing plant communities, current wildlife use and productivity, and seasonal water supplies, are all important factors now being considered before the decision to use drawdown is made as a habitat manipulation technique.

Dikes and levees: Many extensive estuarine areas have effective water control with simple dikes and levees which are used to hold water or to keep water off the area being managed. It is often possible to flood or drain an area by gravity with simple control structures. Thousands of acres of coastal marshes, especially in Louisiana, have natural levees and barriers, which impound adequate amounts of water in years of normal rainfall and tides, but except on limited areas, control of water levels in these marshes is almost impossible. Dikes are used to stabilize levels in marshes where water levels are drastically affected by tides and winds. Other segments of marsh are diked to provide optimum growing conditions for desirable wildlife food plants. Marshes managed in this manner often yield three to five times as many muskrats as undiked adjacent marshes.

Control structures: Most water control structures used in marshes are simple, but effective. Critical factors for effective operation of control structures are the timing of flooding and dewatering, an adequate water supply for flooding, and no flooding during dewatering.

Impoundments, although expensive, have been widely used in the southeastern United States. Also, without pumping facilities, abnormally wet or dry conditions usually result in poor wildlife food conditions, and impoundments can be built only in areas that will support a levee. Thus, other less expensive methods that have a wider application are being used to improve coastal marshes for wildlife. Two of these are weirs and earthen plugs.

A weir is a structure placed in the drainage system of a marsh and set about 6 inches below the level of the surrounding marsh. This permits the flow of tidewater in and out of the marsh, but prevents the drainage of the marsh. Weirs are particularly valuable in producing desirable aquatic vegetation in marsh ponds and lakes, and have already been used

in managing over 250,000 acres of salt and brackish marshes along the south Atlantic and gulf coasts.

Earthen plugs in tidal marshes are being used for a type of management similar to that obtained by the use of weirs; however, the plugs rise several feet above the surrounding marsh level. Thus, normal tides are not permitted to enter the system and excess rainwater must run around the plug through the surrounding marsh or other depression. Most of the plugs appear to be ineffective for improving plant conditions for wildlife, but they do provide permanent water for wildlife and greatly improve access to the marsh by hunters, trappers, and fishermen.

Pumping: Pumping is used for flooding and dewatering impoundments for wildlife management. This method is usually the most expensive but is also the most reliable. Pumping may be used as a standby or supplementary method to simple inlet and outlet structures. The expenses of pumping are justified in estuarine wildlife management when valuable wildlife species and habitats are involved.

Level ditches and marsh potholes: Level ditches and marsh potholes are constructed to improve estuarine habitat for wildlife. They may be built by draglines, ditching plows and such devices as rotary tillers which have been used experimentally in some Louisiana marshes. Blasting has also been used to create ditches and potholes in extensive marshes.

The purpose of these areas is primarily to open up dense vegetation, to provide a permanent water supply and easier access to the marsh. The latter two objectives are attained easily in most areas, but usage by wildlife is not always assured. Along coastal marshes, ditches constructed with draglines are not usually productive of wildlife until after the first few years because turbidity may restrict growth of aquatic vegetation.

Burning: The marsh has undoubtedly been burned since its origin, first by natural fires caused by lightning and later by Indians as they occupied adjacent high land. As white man settled in and near the marsh, he stepped up the tempo of burning to make his trapping, hunting and traveling easier and to improve grazing conditions for livestock. As the overall picture of periodic burning developed, many people noticed an improvement in the marsh, until today all phases of marsh management include periodic burning.

The major objective of marsh burning is to give some of the more valuable food plants an advantage over those that are less desirable or to remove the dense rough and provide more succulent food for wildlife. Although it sometimes backfires or goes astray this is the optimum goal of marsh burning.

Prior to 1910 along the coasts of Louisiana and Texas, intentional marsh burning was an unforgivable sin; however, by 1926 it was a fairly common practice. The reason for this was the increased interest in alligator hunting. To hunt alligators in those days it was necessary to burn off the marsh to locate the alligator holes. Unknowingly, the alligator hunter was making way for the forthcoming muskrat boom in Louisiana and Texas. Because some trappers were noticing an improvement in marsh conditions after a burn, they adopted the practice until burning was commonplace on the gulf coast by 1940.

In more recent years a number of people concerned with estuarine management have recognized that prescribed burning is another important method of managing for desirable plants. Much of the accumulation of plant growth in the northern marshes is removed by ice, spring floods, and grazing; however, in the southern marshes the long growing season produces a heavier growth, and drastic measures are needed to manage the vegetation. Hurricanes remove the vegetation from huge areas in short periods of time; when storms do not remove unwanted vegetation, fire can be an effective tool. The major objectives of burning are to give some of the more valuable food plants a competitive advantage, to remove the dense rough, to provide more succulent food plants for wildlife, and to create open water areas by burning into the marsh floor. Burning affects both wildlife and plants. Nutrients, especially potassium, calcium, phosphorus, magnesium, and chlorides, are released from vegetation and added to the soil and water. The warm temperatures of the south and the fertilization by the ash following fire stimulates new growth almost immediately, even in winter.

Burning has undesirable as well as desirable effects on marshes. An unburned marsh accumulates a very large amount of fuel; in this situation burning is dangerous. The timing of a burn is important. If a burn is made just prior to a high tide many nutrients may be lost. Heavy vegetation helps prevent erosion, thus, in coastal marshes subject to hurricanes, burning should be delayed until about October 15 when the peak of the storm season is past.

Cover burns, usually made in the fall or winter to open up dense stands of vegetation, produce an immediate change in habitat because they remove the standing vegetation, but they seldom produce a permanent change in vegetative type. Root burns, made when the marsh is dry, damage or destroy the roots of the plants and can change the composition of the vegetation. This type of burn is used to reduce

or remove climax vegetation. However, it can stimulate undesirable as well as desirable plant species. To maintain the same kind of vegetation, a burn made just prior to the growing season is the most effective.

Herbicides: Large scale control of estuarine vegetation is best accomplished by water level manipulation, burning, cutting or by animals. When those methods are not feasible, and especially on smaller areas and for special purposes, herbicides are useful. Herbicides cause relatively little damage to animal organisms in the marsh when those of low toxicity to animals are used, when directions are carefully followed, and when care is taken to avoid spillage and overdosing.

Planting: On estuarine areas drained and later restored, on created areas (such as spoil islands), and on natural areas where desirable water levels have been restored, aquatic plants often return or occur naturally. Where desirable plants are absent or less desirable species are dominant, planting can be an important management tool. Plantings range from seeding cultivated grains to produce food for wildlife, to seeding exposed mud flats following drawdowns, and setting out rooted aquatics. Wildlife prefer a diversity so it is best to plan for a variety of plant species and a proper balance of open water and plants.

Planting is inadvisable where a good stand of species exist, but a paucity of natural vegetation may indicate habitat deficiences. In the coastal marshes where "cat clays" pose a problem with cultivated crops, similar problems are likely to affect plantings for wildlife. In these areas only a quick maturing plant which does not require deep drainage is suitable.

Animals: Both wild and domestic animals can control plants, but usually in different situations. Wildlife, especially when population levels are high, may exert undesirable control on the vegetation and may need to be controlled in order to maintain desirable plant communities.

When populations of muskrats and nutrias are high, their feeding activities may compete with ducks or other wildlife for food plants. At peak populations, the muskrats and nutrias make "eatouts" on some coastal marshes. Eatouts by muskrats, nutrias and geese sometimes create muck-bottomed ponds in tidal marshes and create more open water than is desirable. Eatouts by nutria normally revegetate in one growing season because these mammals feed at the surface, but an eatout by muskrats, which consume roots and all, may require as long as 10 years to revegetate. Because muskrats and nutrias are valuable furbearers, control usually involves offering ample opportunity for their legal harvest and providing trappers ready access, by impoundments and level ditches, to all sections of the marsh.

Grazing by cattle is a well-established practice in coastal marshes. Grazing is economical, usually effective, and does little damage to nesting wildlife.

High populations of fishes, especially bullheads and carp, may create conditions in a marsh that eliminate desirable aquatic vegetation. Some estuarine areas can be successfully managed for fish and wildlife at the same time, but unwanted fish must be controlled. Undesirable populations of fishes can be removed by netting or poisoning. Even when a fish population is not detrimental, the trampling of shoreline vegetation and the disturbance caused by the presence of an excessive number of fishermen may harm wildlife values.

The animal species which perhaps has had the greatest effect on estuarine habitat in the United States, although indirectly, is the salt-marsh mosquito. In attempts to control this species, people have affected the wildlife values of many thousands of acres of coastal marshlands. In the early 1930's the Civilian Conservation Corps, at the request of local communities, began to ditch marshes for mosquito control. Nearly 500,000 acres of valuable marshes from southern New England to Maryland were drained and made nearly useless for waterfowl and other wildlife.

Wildlife agencies and mosquito control agencies have now devised methods of water management that both benefit waterfowl and other wildlife while controlling mosquito populations. The eggs of floodwater mosquitoes are laid only in temporarily dewatered sites. The eggs hatch when high tides or rains reflood the eggs. By diking marshes and keeping them flooded throughout the mosquito breeding season, mosquitoes are effectively controlled, and the impoundments greatly enhance the value of tidal marshes for many species of wildlife. Construction costs for mosquito control impoundments are greater than ditching costs but the benefits are many times greater. These impoundments also provide trapping, crabbing, frogging, and firebreaks.

EVALUATION OF RECENT WILDLIFE MANAGEMENT PROGRAMS

To maintain and increase valuable estuarine wildlife resources in the face of growing pressures to convert estuarine habitats to other uses has necessitated

many activities. These include land acquisition, research investigations, and intensive management programs. The objectives of these activities have been discussed previously. Thus, only results and indicated trends will be discussed below.

Wildlife habitat acquisition: National planning is lacking for estuaries, including their fish and wildlife resources. Without national planning, acquisition of valuable estuarine wildlife habitats has proceeded with only uncoordinated, spasmodic, and piecemeal efforts. Funds available nationally for acquisition of wildlife lands have been limited. Therefore, these funds have been used on a priority basis, but without national planning even the best intentions have resulted in the acquisition of less valuable areas while extremely valuable estuarine wildlife lands have been lost to other land uses. Although acquisition of less valuable wildlife lands is usually cheaper than more valuable habitats, the initial monetary savings are soon nullified by the increased costs of necessary development and management activities.

Indications are that more comprehensive planning for estuaries is in the making in order to more wisely identify, preserve and protect their fish and wildlife resources. The problem of splintered governmental responsibilities and authorities which complicate controlling use of estuarine lands held in trust for the public is now receiving much greater attention.

Wildlife research: Protecting, and even increasing, valuable estuarine wildlife resources requires research results to plan for proper management. Unfortunately, good wildlife research usually takes more time than land administrators are willing to take before initiating management practices. A large amount of good quality estuarine wildlife research has been accomplished largely through the yeoman efforts of a relatively small cadre of wildlife biologists. Unfortunately, the force of their recommendations has not always carried enough weight when management decisions have been made.

Past research on wildlife use of estuarine areas has been localized where important problems existed and where a pooling of interest, effort, and finances made an effective venture possible. The Back Bay-Currituck Sound research project is an example of this type of productive effort. However, nationally there has generally been no provision for the more general survey approach followed by more intense research on local problems according to a logical system of priorities. Ambitious, high quality, research programs have been contemplated in the past, but funding and staffing deficiences have derailed them.

Encouragingly, wildlife administrators appear to be more inclined to provide the cooperation and coordination that is essential to obtain the greatest dividends from a given amount of research funds and effort.

Wildlife management: After acquiring (or establishing some control over) estuarine wildlife habitats, and after having the benefits of good research efforts, the next step is to reach wildlife resource goals by proper management. But what is proper management? This is the big question. The answer should be that level of management required to sustain optimum populations of wildlife and enable maximum enjoyment by the public. We do not know, and have hardly started to fully determine, what management is essential for the welfare of many estuarine wildlife species, or what criteria result in maximum public enjoyment. Only by improving knowledge of these requirements will better management policies be established even though many of the necessary tools and procedures are known. Although many federal, state, and privately controlled estuarine wildlife areas have accomplished much toward these goals, many instances of faulty management still remain.

Overmanagement, which wastes time, effort, and money, exists in many forms, e.g., excessive diking, pumping, farming, plant control, pothole blasting, and other practices. There are areas where most wildlife biologists concede that intensive management is not presently required by wildlife or the public, but they have been pressured into putting the land to use. At times, the explanation is offered that management activity is required to justify retention of certain lands. This type of overmanagement is deplorable. It rejects the idea of a land bank whereby the conservation agencies hold strategic parcels of land, and manage them only when the need has been demonstrated. This common fault of attempting to manage all lands under jurisdiction is costly and unnecessary.

Undermanagement of lands administered by wildlife agencies is probably less commonly encountered than overmanagement. It is less costly in money and effort, but it adds little to our knowledge. Probably the most common example of undermanagement is the lack of water drawdown even when adequate facilities are available. Apparently the fear of failure or of causing irreparable harm if stable water levels are not maintained, prevents some managers from experimenting.

Mismanagement is a product of ignorance, or lack of sufficient manpower, money, or incentive to do the job properly. Unfortunately, mismanagement is widespread.

Misdirected weed control programs can be found throughout the country. In some instances eradication programs have been directed to the control of useful wildlife foods, e.g., *Hydrochloa* or *Myrica*. Eradication programs such as the alligatorweed program often operate more on fancy than on fact. Early control of pest plants that spread rapidly and persist, e.g., Eurasian watermilfoil, water hyacinth, and water chestnut, is important, but there are examples of undue delay in action programs. The ultimate value of control is concerned not only with killing the target plant, but also with the plant communities that follow. In areas where maidencane growth succeeds alligatorweed, little has been accomplished by control.

Poorly planned plant introductions are probably not as common as they once were, when transplanting was in vogue 20 to 30 years ago. There are still a few private individuals who purchase wildlife foods and unwittingly plant them in habitats where they already occur naturally.

In summary, wildlife management on estuarine areas is far from being an exact science. A detailed, critical evaluation of all estuarine wildlife management areas would probably show that most are being well managed with the funding and manpower available. However, there are enough examples of mediocre or poor management to indicate that there is much room for improvement. The knowledge bank of estuarine wildlife management techniques is increasing, yet there are enough knowledge and communication gaps to cause many problems in trying to provide wildlife with the necessary variety and quantity of food, water, and protective cover. Lack of overall, coordinated management among all interested parties hinders the most effective management of estuarine wildlife. On the brighter side, there now appears to be meaningful effort to correct this severe problem.

FUTURE TRENDS AND NEEDS IN ESTUARINE WILDLIFE MANAGEMENT

One crucial dimension of estuarine habitat relationships must receive much more consideration if the future needs of wildlife are to be met. This is, one wetland community may contribute nutrients to another nearby, or to another distantly located. Highly productive estuaries and coastal marshes are surely the lifeline of our entire coastline and adjacent seas. Resource managers must be acutely aware of these important relationships in order to avoid misjudging the values of our dynamic estuarine communities. As we are painfully learning, energy and nutrient cycles and food webs require greater understanding.

Many of our present environmental problems result from plans executed project-by-project, without relating individual actions to an entire estuary or watershed. This case-by-case approach is the genesis of many problems (including wildlife resources) plaguing estuarine areas. Broadly integrated, rather than single purpose, planning is required for estuaries to designate where and what developments can be permitted without damaging the resource base. Estuarine landscape must be recognized as one major ecosystem with interdependent components and functions and not be subjected to insidious destructive and resource-degrading activities. With our increasing population and associated demands on resources, constructive national action is imperative.

Communication, coordination, and cooperation are the cornerstones on which science, industry, government, and citizens must build to attain a viable solution to the multi-user problems involved in equitable and effective estuarine management. Wildlife values are only a part of our total estuarine values, but they must be considered. Certainly, broad-scale estuarine planning has been discussed previously in this overall report. Thus, only the plea that our wildlife resources be justly considered will be made here along with the thought that we stand on the threshold of decision. Procrastination is no longer either profitable or possible. Our national estuarine problems must be solved with national planning and national efforts.

Following is a brief listing of some of the needs of estuarine wildlife research and management.

- Initiate a comprehensive national survey of the fish and wildlife resources of estuaries and their habitats.
- Identify and delineate those areas of special estuarine significance in need of federal, state, or local protection through land control and management, or through another vehicle such as an "estuarine authority."
- Plan a program of research and experimental management on coastal wildlife refuges and perhaps on national parks and seashores as well. The basis of this approach is that the coastal wildlife refuges offer natural bases for inventory, research, manipulation, experimental management, and rehabilitation. These refuges have land, water, marshes, fish, birds, mammals, and people with local knowledge, and a wide variety of problems associated with environmental manipulation. Coastal national parks and seashores may also offer the same opportunities.
- The entire field of habitat rehabilitation prom-

ises to yield great rewards but unfortunately has been sadly neglected. We know that thousands of acres of estuarine habitat have been damaged and destroyed and that the future promises an increase of this problem. It is time now to stop, and if possible, to reverse this destructive trend. Habitat rehabilitation certainly is one way to accomplish this goal.

• There is urgent need for an accelerated research program to give better understanding and better tools for management. Among these needs is a far better knowledge of the overall ecological relationships of total communities of organisms.

• More precise knowledge of the interrelationships of the tidal flats, marshes and periodically inundated semi-upland is needed. To what extent are our aquatic resources dependent upon these higher elevated tidal zones? To what extent does the mismanagement of these higher zones affect the permanent water areas and their productivity? To what extent does one wetland community contribute to another?

• The specific ecological requirements, degree of adaptability, life histories, food, nesting and other habits, social behavior patterns, competition, enemies, limiting population factors of abundance or population dynamics, and many other aspects of many wildlife species are known only in part. Research here surely is needed and some of it is urgent.

• Research on the economic, recreational and sporting values were urgently needed on all estuarine commercial products long before those resources were eliminated by dredging, filling and pollution. Research is now needed on how to safely restore and effectively manage the potential resources that remain. Socio-economic studies are needed to establish more firmly public values of specific and associated renewable resources. Otherwise, we cannot objectively appraise these renewable resources against other proposals for development of those areas. Too many local areas have been destroyed without thought or realization of the values being eliminated.

• Revised procedures or legislation are needed to permit adequate time to conduct wildlife studies, analyze project effects and devise protective and enhancement measures for all estuarine projects.

• With the demands for fresh water diversion, dams and more dams on all our rivers, it is apparent that less and less fresh water is going to reach the sea coast and the drainage water that does enter will likely be polluted and contain concentrations of salts and other minerals. The proposal to drain water from the Sabine down the Texas coast to the lower Rio Grande Valley is expected by most people to prevent the "loss" of fresh water into the coastal estuaries and gulf. It is obvious that to the extent that fresh water is prevented from reaching the gulf, the gulf seawater will encroach into the estuaries and accordingly change them. We need to know the critical limits to which fresh water can safely be diverted. We need to know the salt tolerance of the various organisms—commercial, sporting and food chain species in the estuaries, and we need to know what effects will result from diversion of fresh water that normally enters the various estuaries. This is an urgent research need and such studies should be generously supported.

• Human population increases will require new approaches and intensive management of species now harvested or those little used.

• Lastly, perhaps there is urgent need for studies to improve better public relations and people management as they affect our estuarine system.

Much destruction of our valuable estuarine wildlife habitats has already taken place, and many estuarine uses now being planned will destroy or damage a number of our remaining areas. Only a concerted national effort now will turn the tide. Surely we have the desire and pride to do this.

IMPACT OF ESTUARINE POLLUTION ON BIRDS

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ABSTRACT

Pollution of estuaries affects bird populations indirectly through changes in habitat and food supply. The multi-factor pollution of Chesapeake Bay has resulted in diminution of submerged aquatic plants and consequent change in food habits of the canvasback duck. Although dredge-spoil operations can improve wildlife habitat, they often result in its demise.

Pollution of estuaries also affects birds directly, through chemical toxication, which may result in outright mortality or in reproductive impairment. Lead from industrial sources and roadways enters the estuaries and is accumulated in tissues of birds. Lead pellets deposited in estuaries as a result of hunting are consumed by ducks with sufficient frequency to result in large annual die-offs from lead poisoning. Fish in certain areas, usually near industrial sources, may contain levels of mercury high enough to be hazardous to birds that consume them. Other heavy metals are present in estuarine birds, but their significance is poorly known. Oil exerts lethal or sublethal effects on birds by oiling their feathers, oiling eggs and young by contaminated parents, and by ingestion of oil-contaminated food. Organochlorine chemicals, of both agricultural and industrial origin, travel through the food chains and reach harmful levels in susceptible species of birds in certain estuarine ecosystems. Both outright mortality and reproductive impairment have occurred.

INTRODUCTION

Millions of people live in communities bordering the estuaries. They deposit their wastes in the oceans, bays, and rivers on the age-old assumption that the ocean has an infinite capacity to remove, store, and cleanse. The error of this assumption is now evident. Kinds of pollution are numerous and their sources divergent. They include agricultural pesticides, industrial wastes, sewage effluents, abnormal changes in water temperature, and soil eroded from disturbed lands. Even the hunters, concentrating on shrinking waterfowl areas, annually increase the toxic burden of lead shot in the environment. We will take examples from a few of these in relation to certain kinds of birds whose lives depend upon the estuarine ecosystem.

Pollution of estuaries affects bird populations indirectly through changes in habitat and food supply; these changes are widespread, not immediately apparent, and, in practice, may not be reversible. The kinds of pollution include turbidity, sedimentation, eutrophication (enrichment by nutrients), and abnormal changes in water temperature. They also include pollution by oil and chemicals. These factors cause changes in the kinds and numbers of animals and plants in the biotic community. For example, prior to the 1950's, the canvasback duck fed primarily on parts of submerged aquatic plants in the Chesapeake Bay. Since that decade, the canvasback's diet in the bay has changed completely, until now it feeds almost entirely on small clams and occasionally on other animals that are part of the detrital food chain (Fig. 1). Similar changes in the Illinois River are believed responsible for the decline of the canvasback and other species in the area (Mills et al., 1966). Different species of waterfowl have greatly different diets, including both animals and plants.

Herons, in contrast, feed only upon animals, but these may occupy several levels of the carnivorous food chain, from aquatic insects, crustaceans, and molluscs, to fish. Pelicans and ospreys feed almost entirely upon fish, the top of the aquatic chain; and eagles eat both fish and birds (Fig. 2). Pollution-induced changes in the populations of the food organisms will inevitably change the food habits of birds and may affect populations.

Physical changes may destroy or drastically alter the estuaries. Dredge-spoil operations, for example, may have either detrimental or beneficial effects. For example, in the saline marshes of New Jersey,

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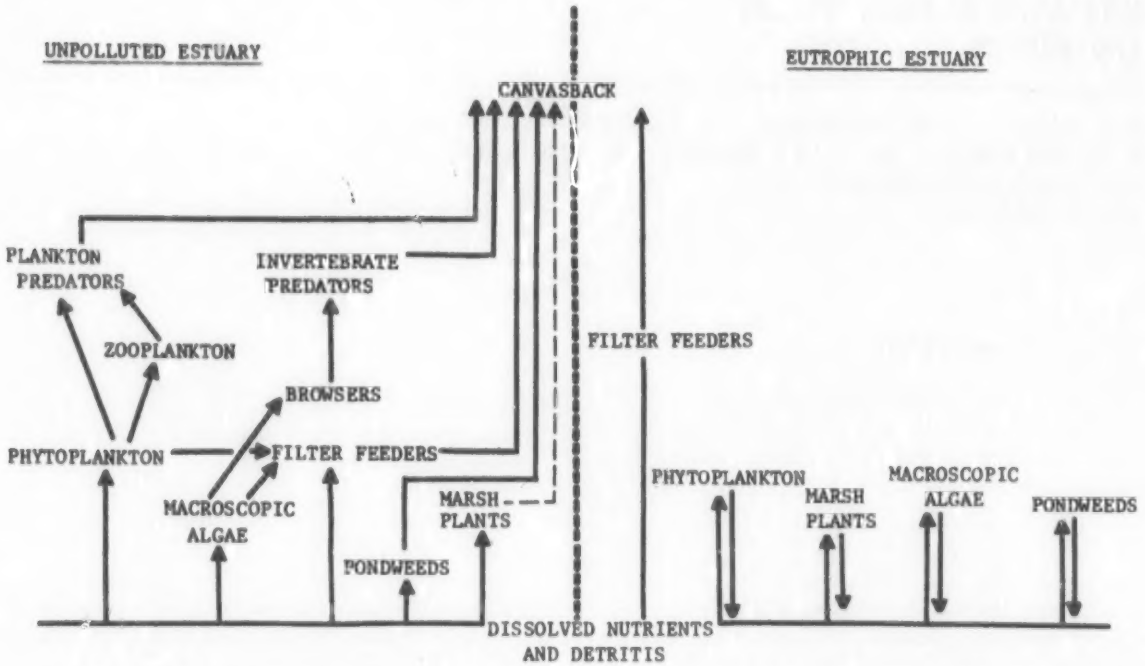

FIGURE 1.—Food chains of canvasback ducks in clean water and eutrophic estuaries. Multiple pollution of Chesapeake Bay has changed the entire biotic community. The canvasback duck has adapted by changing its diet, but the cost may be reflected in reduced wintering populations on the bay.

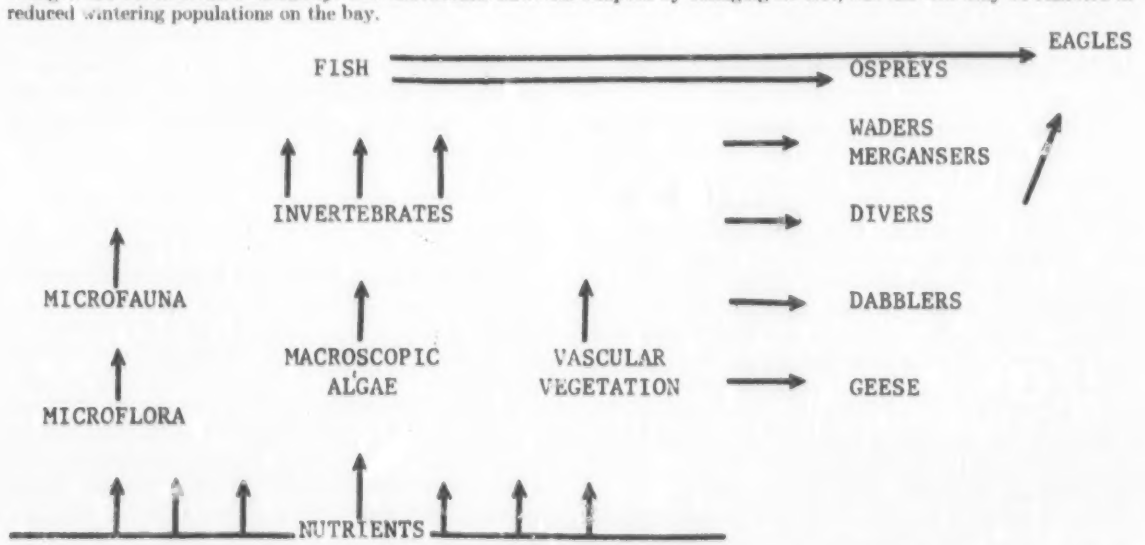

FIGURE 2.—Flow of nutrients through the estuarine food chain. This simplified diagram shows the diverse food habits of waterfowl, and the successively more restrictive requirements of wading birds, ospreys, and eagles.

valuable plant communities such as *Spartina alterniflora* may be destroyed by dredging and subsequent invasion by *Phragmites communis*, which is of only small value to wildlife populations. In contrast, spoil deposits can increase plant diversity. On the eastern shore of Maryland and Virginia, in New Jersey, and on the Outer Banks of North Carolina, dredge-spoil operations on the inland waterway have created habitat for gulls, terns, black ducks, willets, herons, ibises, and egrets. Proper management of

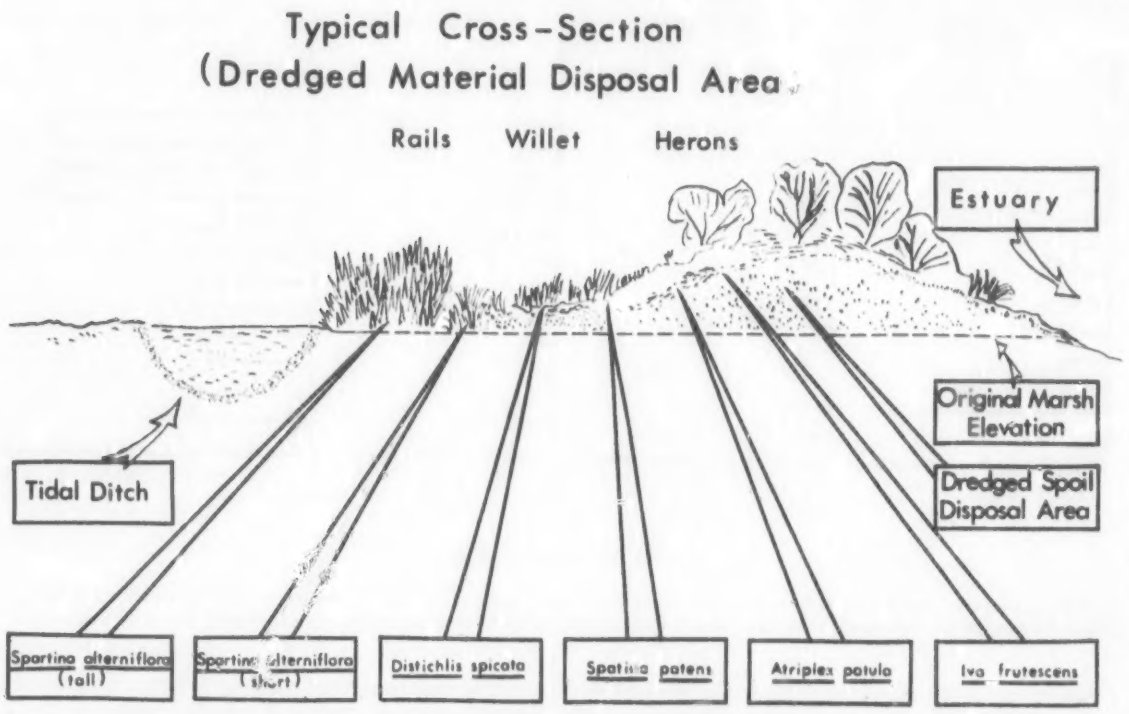

FIGURE 3.—Plant succession and nesting cover on spoil banks on the eastern shore of Virginia. Dredge-spoil operations often destroy or drastically alter estuarine communities, with seriously detrimental effects on bird populations. Proper management can ameliorate damage in some areas.

dredge spoil can be beneficial to wildlife, but development of the techniques is in its infancy (Fig. 3).

Pollution of estuaries affects birds directly through chemical toxication. High levels of chemicals may kill birds outright but lower levels may have more insidious effects, impairing both reproduction and survival. Both may be critical to survival of populations.

LEAD

Lead poisoning has been recognized as a cause of waterfowl mortality since the turn of the century. Ducks that eat lead shot experience serious physiological disturbances of the digestive, circulatory, and nervous systems, which may eventually result in death. Waterfowl mortality from this cause has been estimated as 1.5 million birds per year.

In 1972, the U.S. Fish and Wildlife Service initiated a study to examine the geographic distribution of lead levels in several species of waterfowl throughout the United States. The survey was made by examining the lead levels in the wingbones of immature ducks. Bone was selected because lead uptake by bone is rapid and loss is extremely slow. Lead levels in the bone, therefore, represent the bird's total history of exposure. Wingbones were used because statistically planned samples of wings were readily available from other studies in which wings of many species are obtained annually from hunters to assess reproductive success of the birds and to help measure the harvest. Young birds were sampled because they would be making their first southward migration and therefore would reflect the exposure of a single season. Mallards were the primary species sampled, because of their almost nationwide distribution and availability.

Lead in wingbones of immature mallards ranged from less than 0.5 ppm to greater than 400 ppm on a dry weight basis. Levels were highest in states of the Atlantic flyway, lowest in the Central flyway, and intermediate in the Mississippi and Pacific flyways (Fig. 4). Levels in black ducks from the northeastern states were similar to those in mallards. Mottled ducks from Florida, Louisiana, and Texas had the highest levels of any species from any area. It was evident that a high proportion of the waterfowl population is exposed to elevated levels of lead.

Over most of the United States, there is strong

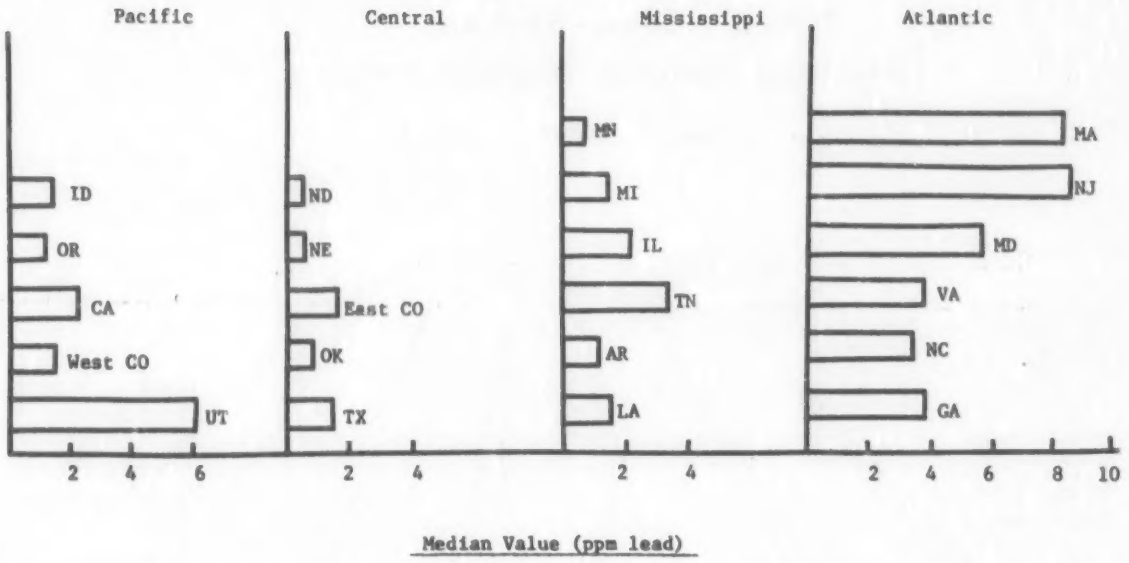

FIGURE 4.—Lead in mallard ducks. Geographic differences in lead exposure are shown by analysis of lead content of wingbones. Highest exposure is in the east, where marshlands used by waterfowl receive municipal and industrial lead as well as lead shot.

evidence that the major source of lead in ducks is ingested shotgun pellets. Each year, 2 million waterfowl hunters shoot more than 3,000 tons of lead into marshes, lakes, and estuaries. Many of these spent shot are eaten by the birds as if they were seeds or grit. The shot are ground in the gizzard, and much lead is absorbed by the body. Results of a survey of lead shot in gizzards showed a geographic distribution very similar to that of lead in wingbones (Bellrose, 1959).

However, lead from other manmade sources may account for some of the lead in the bones. This is particularly true of mallards and black ducks from northeastern coastal states, where a large percentage of the wingbone samples contained moderate to high levels of lead. In this region, hunting often is concentrated in areas that also receive lead as an industrial or municipal pollutant, and lead in the bone from the various sources is not easily separated.

OTHER HEAVY METALS

Estuaries are repositories for many other heavy metals besides lead, since these areas receive the effluent from numerous industrial areas. Heavy metals are a part of the complex of pollution that alters the energy flow and food chain composition. The effects of heavy metals on birds are not at all well understood.

Mercury is a cause for concern in some areas and has been most studied. Levels of mercury increase through the various stages of the food chain. Ducks that feed more upon animal matter (divers) have higher levels of mercury than those that feed predominantly upon vegetation (dabblers). This is shown in the distribution of mercury in samples of divers and dabblers from Wisconsin (Kleinert and DeGurse, 1972) and from Pacific flyway estuaries (Baskett, 1975). Mergansers, because of their fish-eating habits, show the highest mercury levels (Fig. 5).

The eggs of wild mergansers often contain levels of mercury that have impaired the reproduction of captive mallards and black ducks (Heinz, 1974; M. Finley and R. Stendell, personal communication), but it is not known whether the mergansers are affected, because neither field nor laboratory studies have been made.

Bald eagles, which eat both fish and birds, occasionally contain high levels of mercury (Mulhern et al., 1970; Belisle et al., 1972).

OIL

Spills of major extent may oil and kill thousands of birds and disfigure beaches. Spectacular accidents, however, constitute only a small percentage of the 5 million metric tons that is estimated to be the annual global input of oil to the oceans.

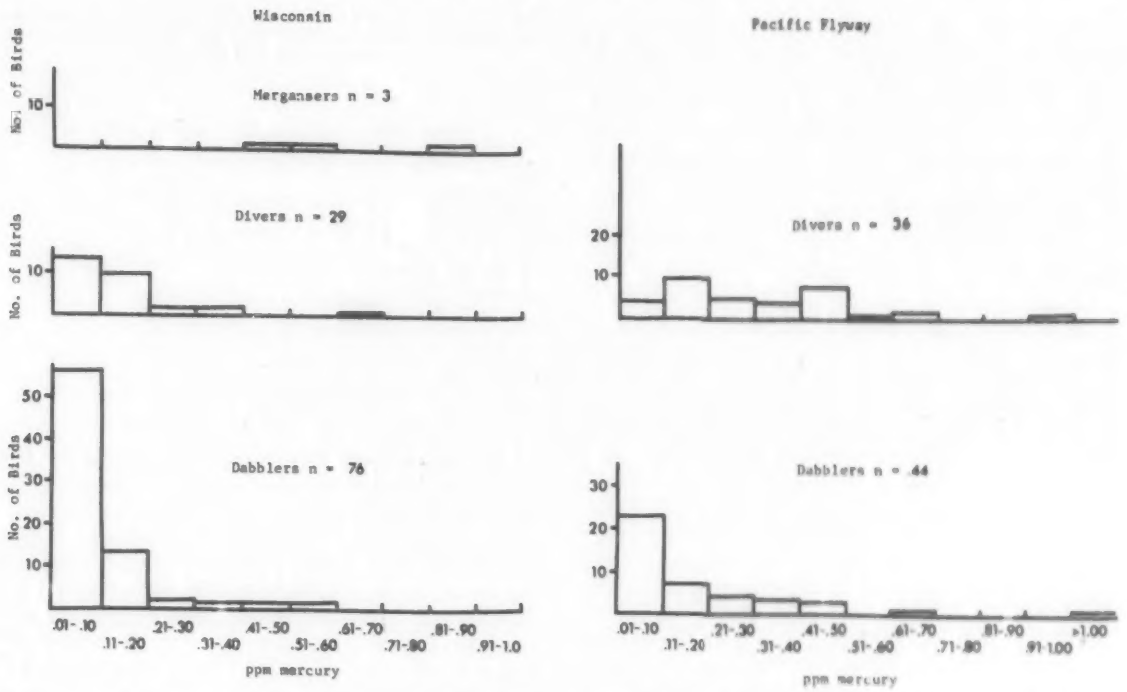

FIGURE 5.—Mercury in ducks from Wisconsin and from Pacific estuaries. Diving ducks which feed more upon animal material accumulate more mercury than do dabbling ducks which feed predominantly upon vegetation (Kleinert and DeGurse, 1972; Baskett, 1974).

Birds may be affected by oil directly, through feather-oiling, by exposure of eggs to oiled feathers, and by ingestion of oil. They may die as a result of direct exposure to oil even when the oil is essentially gone from the feathers. The damage results from the ingestion of oil during preening or during intake of food items that are coated with oil. Oil is found in tissues of birds in oil-spill areas even when feathers are not oiled (Burns and Teal, 1971). In the San Francisco spill of 1971, grebes, murres, and loons died more rapidly than other birds and the duck species appeared most hardy (Snyder et al., 1973). Various pathological conditions and signs of debilitation were present in oiled birds. Delayed feather damage also may occur (Bourne, 1974). Oil ingestion at levels obtainable from oiled plumage inhibited egg laying of mallard ducks and had other physiological effects (Hartung, 1963, 1964, 1965). A thin film of oil will prevent eggs from hatching and could be introduced by the incubating hen (Hartung, 1965; Kopischke, 1972). Ingested oil may interfere with the intestinal absorption of water by ducks that depend upon saltwater and result in death from dehydration (Crocker et al., 1974).

ORGANOCHLORINES

Manmade chemicals have become an integral part of estuarine ecosystems throughout the world. The organochlorines of agricultural and industrial origin travel through the food chains and follow the energy cycles of all living organisms. Species differ greatly in susceptibility to harm. Some species, such as fiddler crabs, are so easily killed by DDT that they may be lost from local faunas. Other species, such as snails, are less easily harmed and so serve as accumulators. Organochlorines enter the body of birds primarily through the foods they eat. Birds that eat fish and other birds generally accumulate higher amounts than do birds that eat seeds and vegetation.

Predatory and fish-eating birds that live near the estuaries and depend upon the estuarine food chain accumulate a wide variety of organochlorines in their tissues and transmit them to eggs and young. The principal chemicals—those that occur most frequently and in the greatest concentrations—include DDE, dieldrin, and PCBs (polychlorinated biphenyls). Many other kinds occur less frequently.

The effects also are various. Those of DDE are best documented, for this compound in small amounts thins eggshells and impairs reproduction of many kinds of birds, and these effects have been verified in numerous experimental and ecological studies. The relationships of DDE and other organochlorines to different species of estuarine birds can best be considered through examples.

Bald Eagles

Since 1947, eggshells of a number of species of birds of prey have thinned both in the United States and in other parts of the world (Ratcliffe, 1967; Hickey and Anderson, 1968). Bald eagle eggs from Brevard and Osceola Counties, Fla., were among those whose shells thinned significantly; the bald eagle population was declining in the area as was its reproductive success. Declines in populations and reproductive success of bald eagles nesting on the west coast of Florida had been reported earlier (Broley, 1958). Thinned eggshells are less able to support the weight of the incubating bird and are more susceptible to breakage, so that fewer eggs are hatched. The hypothesis was advanced that eggshell thinning was caused by the introduction of organochlorine insecticides, such as DDT, into the environment. This hypothesis was substantiated in later years by the results of experimental studies with several species; these studies also showed that even the unbroken thin-shelled eggs hatched poorly. American sparrow hawks (a species related to the bald eagle and osprey) that were fed diets containing DDT and dieldrin in combination, as well as DDE alone, laid eggs with shells that were significantly thinner than those of undosed sparrow hawks (Porter and Wiemeyer, 1969; Wiemeyer and Porter, 1970).

Bald eagles found dead in the field have been monitored for the presence of organochlorine insecticides since 1964, and for PCBs since 1969 (Reichel et al., 1969; Mulhern et al., 1970; Belisle et al., 1972; Cromartie et al., 1974). Their tissues contained a wide range of concentrations of many different chemicals. Some contained high amounts. The most notable finding was that 8 of 17 (47 percent) of the bald eagles from southeastern coastal states (Maryland, Virginia, South Carolina, Florida) were suspected to have died of dieldrin poisoning. The four cases from Maryland and Virginia were from tidewater areas of Chesapeake Bay (Cromartie et al., 1974). Reproductive success of bald eagles in this area has been poor (Abbott, 1973). Only 11 of 173 bald eagles (6 percent) from other areas of the United States had such high levels of dieldrin.

Table 1.—Organochlorine residues in eggs of bald eagles from estuarine areas. The high residues in eagle eggs from Maine parallel poor reproductive success in that area. (Wiemeyer et al., 1972)

Area and year	n	Residues ppm wet weight		
		DDE	Dieldrin	PCB
Alaska				
Kodiak—1969	7	1.9	0.10	2.2
Admiralty—1970	5	2.9	0.06	1.1
Florida				
Everglades—1968	6	11.0	0.21	n.a.[1]
Lee County—1969	2	18.0	1.1	12.0
Maine 1967–69, 1974	11	22.0	1.1	30.0[2]

[1] Not analyzed.
[2] Only 1969 and 1974 eggs were analyzed for PCB, therefore the sample size is 6.

Bald eagle eggs from populations near several estuarine or salt water areas have been collected for analysis of environmental pollutants (Krantz et al., 1970; Wiemeyer et al., 1972). Eggs from Kodiak Island and the Admiralty Island area of Alaska had the lowest levels of pollutants (Table 1). Those from Florida and Maine had considerably higher concentrations. The poor reproductive success in many of the eagle nests in Maine probably is the result of the high concentrations of DDE, dieldrin, and PCBs in the eggs. Reproductive success of the eagle populations in Alaska (Sprunt et al., 1973; Robards and King, 1967) and in Everglades National Park, Fla., (Sprunt et al., 1973) appears to be adequate to maintain those populations, whereas the Maine population has been declining for a number of years. Moderate eggshell thinning (about 10 percent) has occurred in each of the recent samples mentioned above, with the exception of those from the Admiralty Island area of Alaska. Eggshell thinning has also been reported for bald eagles in southern Texas (Anderson and Hickey, 1972).

Ospreys

The osprey population in estuarine areas along the coast of Connecticut, particularly at the mouth of the Connecticut River, has been one of the better studied declining populations. Seventy-one active osprey nests were present near the mouth of the river in 1960 (Ames and Mersereau, 1964), whereas only five active nests remained in 1969 (Wiemeyer et al., 1974). This population crash was accompanied by poor reproductive success. Results of studies conducted in 1968 and 1969 indicated that the most probable cause of the poor reproduction was the contamination of the birds and their eggs (Wiemeyer et al., 1974). Dieldrin, DDE, and PCBs were sus-

Table 2.—Organochlorine residues in eggs of ospreys from estuarine areas. High residues in Connecticut eggs are associated with reproductive failure and population decline. (Wiemeyer et al., 1974)

Area and year	n	Residues ppm wet weight		
		DDE	Dieldrin	PCB
Connecticut				
1964	6	9.9	0.68	13.0
1968–69	10	8.9	0.61	15.0
Massachusetts				
1972–73	7	4.6	0.17	10.0
New Jersey				
1970, 1972	8	14.0	0.20	8.8
Maryland				
Smith Island				
("fresh") 1973	10	3.5	0.06	3.0
Potomac				
("failed to hatch")				
1968–69	12	3.4	0.25	2.6
("failed to hatch")				
1971	8	3.2	0.24	4.6
("failed to hatch")				
1972	9	3.0	0.30	6.3
("failed to hatch")				
1973	13	3.2	0.15	9.9
("fresh") 1973	20	3.7	0.16	11.0
Florida				
Florida Bay 1973	10	0.90	0.02	1.5

pected of being important factors in the declines. Eggshells from this population had thinned significantly, by about 18 percent, since the 1940's. One adult osprey from Connecticut was suspected of dieldrin poisoning, and another found dead in South Carolina had levels that probably contributed to its death.

Ospreys nesting along the Potomac River in Maryland appeared to reproduce at a near-normal rate in the 1960's; these birds contained much lower residues of DDT and its metabolites, dieldrin, and PCBs in their tissues and eggs than did the Connecticut ospreys during those years (Wiemeyer, 1971; Table 2). Fish used by ospreys as food in the Potomac River area also contained much lower levels of pollutants than those in the Connecticut River area (Wiemeyer et al., 1974). Reproductive success of ospreys on the Potomac River in the early 1970's fell to about one-half to two-thirds of the success needed to maintain the population, although no decline in number of breeding pairs was observed (Wiemeyer, 1971; 1974). Eggshell thinning in the Potomac population in 1973 averaged about 15 percent. PCBs residues in the eggs increased nearly four-fold between 1968–69 and 1973. Residues of DDT and its metabolites and dieldrin in eggs from this area remained relatively unchanged during the same period.

Osprey populations also have declined in Rhode Island (Emerson and Davenport, 1963), New York (Peterson, 1969), and New Jersey (Peterson, 1969; Schmid, 1966). DDT and metabolites and PCBs were high in eggs collected in New Jersey in recent years, and eggshell thinning averaged 12 percent. A small sample of eggs collected earlier had shells that had thinned an average of 25 percent (Hickey and Anderson, 1968).

Reproductive success of ospreys nesting at Martin National Wildlife Refuge on Smith Island in Chesapeake Bay has been excellent (Rhodes, 1972). Residue levels in the eggs are generally low, with the exception of DDT and its metabolites, which were similar to the levels in the eggs from the Potomac River population. Eggshell thinning approached 20 percent in 1973 despite an apparently normal rate of reproductive success. Reproductive success remains high for a population nesting in the Florida Bay area of southern Florida (Henny and Ogden, 1970). Eggs collected there in 1973 showed no shell thinning, and concentrations of pollutants in the eggs were very low. Eggshell thinning was reported for small samples of osprey eggs collected in Florida in 1949 and 1960 (Anderson and Hickey, 1972).

Waterfowl

Organochlorine pesticides and industrial pollutants in ducks are periodically surveyed nationwide to identify trends of pollutants in time and space (Heath and Hill, 1974). Approximately 5,200 wings were involved in the survey during the 1969-70 hunting season. Pools of wings of adult mallards and black ducks from the 48 conterminous states were analyzed for DDE, DDT, DDD, dieldrin, PCBs, and mercury (Fig. 6). All except PCBs were highest in the two coastal flyways, intermediate in the Mississippi flyway, and lowest in the Central. PCBs exhibited a somewhat different geographic pattern; residues were highest in the Atlantic flyway and generally diminished westward. Black duck wings from New Jersey and New York that were analyzed individually showed that birds taken in coastal areas contained higher levels of DDE than those from inland areas. Levels of DDE in duck wings in the 1965–66 survey were similar to those in 1969–70.

Populations of some species of waterfowl appear to be declining. One example is the black duck population along the Atlantic coast that has been declining since the mid-1950's. The cause of the decline is not known, but age ratios in the harvest suggest that reproductive success is adequate. Black ducks are characteristic of a wide variety of habitats from freshwater impoundments to coastal salt marshes,

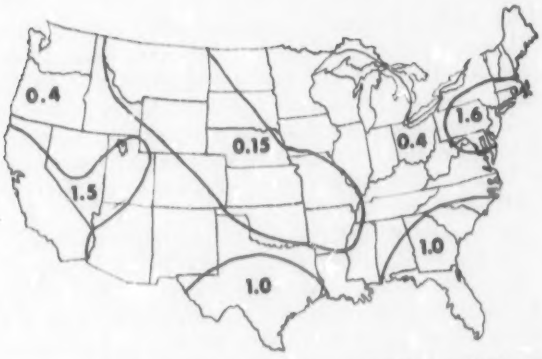

FIGURE 6.—Nationwide distribution of DDE in mallard and black ducks. Residues in wings show geographic patterns, with highest residues in the coastal flyways (Heath and Hill, 1974).

including estuarine river marshes as well as fresh, brackish, and salt estuarine bay marshes, and habitat changes seem insufficient to explain the decline.

Several studies have been made to help determine whether DDE could have adversely affected populations. In a 1971 survey of residues, black duck eggs were collected from 61 nests along the Atlantic seaboard from Maryland to Nova Scotia (Longcore and Mulhern, 1973). One egg from each nest was analyzed for organochlorine pesticides. DDE was detected in all eggs; residues ranged from a trace (<0.05 ppm) to 14.0 ppm on a wet-weight basis. DDE in eggs from Maine, New York, New Jersey, and Delaware averaged greater than 1.0 ppm. Dieldrin (up to 0.81 ppm) and PCBs (up to 6.9 ppm) were present in almost all eggs. The residues of DDE were lower than those in eggs collected from Atlantic states in 1964. The lower residues may reflect the reduced use of DDT in urban and agricultural areas in the 1960's and the discontinuance of the practice of spraying marshlands with DDT for insect control.

In an experimental study, black duck hens fed dietary doses of DDE (10 ppm dry weight) laid eggs with thinner shells than those fed untreated food (Longcore et al., 1971). A number of eggs with thinned shells were crushed or cracked during incubation; such eggs rarely hatched. Embryonic mortality and early mortality of ducklings from dosed black duck hens were significantly greater. Similar effects, although less pronounced, resulted from a dietary dosage of 3 ppm of DDE. The initial field survey in 1964 revealed that the eggs of wild black ducks contained residues comparable to those found in eggs of captive hens fed 3 ppm. The eggshell thickness of eggs collected in 1964 was significantly less than the shell thickness of eggs from the pre-DDT era. The later survey in 1971 revealed that shells were only slightly thinner than those collected before DDT use, and residues were generally lower than levels found in eggs from the 1964 survey.

An experiment to test the effects of DDE on salt-gland function suggested that this compound could be detrimental to survival of ducks in habitats of moderate or high salinity (Friend et al., 1973). Salt glands are the main route of sodium chloride excretion in marine birds. The experiment showed that sublethal levels of DDE suppressed salt gland secretion in immature mallards not previously exposed to salt. There were no adverse effects on mallards whose salt glands had been previously stimulated by low-level salt exposure. It is possible that young birds exposed to moderate levels of DDE, making their first migration from the breeding grounds to coastal estuaries where they experience their first exposure to salt, could face an inability to eliminate toxic levels of salt taken in while feeding.

Brown Pelicans

The brown pelican has shown some of the most interesting and meaningful relationships concerning the influence of pollutants on eggshell thinning, subnormal reproductive success, and population decline (Fig. 7).

This colonial species nests in estuaries from North Carolina to the Amazon River on the east coast and from southern California to Chile on the west coast. Eggshell thinning occurred in every colony of brown pelicans studied in the United States (Blus, 1970; Blus, Neely, et al., 1974; Keith et al., 1970; Blus, Belisle, et al., 1974) and in most of the colonies studied in Mexico (Keith et al., 1970; Jehl, 1973). In 1969, a catastrophic situation was found in the only colony of the California brown pelican that is located in the United States. Eggshells of these pelicans on Anacapa Island, located in the Pacific Ocean several miles off Los Angeles, were so thin that they would break soon after laying. Average eggshell thinning ranged from approximately 35 percent (Blus et al., 1971; Keith et al., 1970) to 50 percent (Risebrough et al., 1971). In 1969, residues of DDE in the egg ranged from 40 to 140 ppm (fresh wet weight) (Blus, Belisle, et al., 1974). These residues of DDE were some of the highest ever recorded in wild birds. By use of stepwise regression analysis, it was shown that DDE accounted for essentially all of the eggshell thinning in the brown pelican (Fig. 8). Even small amounts of DDE, such as those found in eggs from certain parts of Florida, were shown to induce eggshell thinning (Blus et al., 1971; Blus et al., 1972a; Blus et al.,

FIGURE 7.—Two downy pelicans in a nest in South Carolina. Brown pelicans are very sensitive to organochlorine pollutants, particularly DDE. Eggshell thinning and reproductive failure were associated with these agents. Reproductive success has improved as residues have declined.

1972b). In Florida, eggshell thinning in most colonies was less than 10 percent and eggshell thickness in some lightly polluted areas, such as Florida Bay, was near normal. There also was a relationship between low levels of DDE and dieldrin in the egg and hatching success (Blus, Neely, et al., 1974).

Brown pelicans are a sensitive indicator of certain forms of environmental pollution and have shown marked improvement in reproductive success within the past two years as residues have declined. For example, about 0.92 young fledged per nest in the California colony in 1974 compared to less than 0.01 in 1969 when about four young were raised in the entire colony. During the same period, residues of DDT and metabolites in the estuaries near the colony and in the pelicans decreased dramatically (D. Anderson, personal communication). Residues of organochlorine pesticides and their metabolites also have declined markedly and reproductive success has vastly improved to an essentially normal level in the South Carolina colonies.

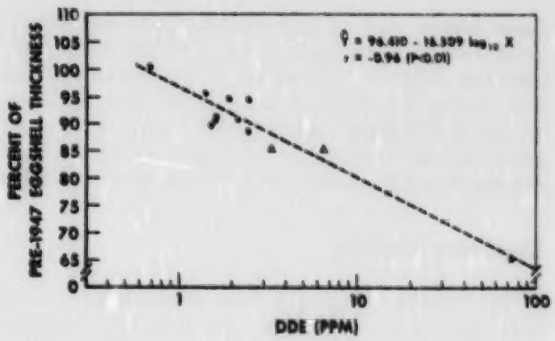

FIGURE 8.—Association of DDE residues in brown pelican eggs with changes in shell thickness. Data are from nine colonies in Florida (●), two colonies in South Carolina (Δ), and one colony in California (*) (Blus, Belisle, et al., 1974).

At one time, Louisiana contained more pelicans than any other state, probably in excess of 10,000 breeding pairs. They disappeared in the 1960's and did not return until reintroduced from Florida in recent years. Birds in this small colony bred successfully in 1971.

In Florida, pelicans have maintained their numbers over the past seven years, and seem to have normal reproductive success. Residues of organochlorines are generally low.

In the small North Carolina colony, reproductive success has been excellent in the past two years and the birds may be increasing in numbers.

Although there are vast improvements in reproductive success of the brown pelican in most parts of the U.S., a normal level has not yet been attained in Louisiana or California. This species is especially sensitive to certain forms of pollution, and its populations should be followed closely.

Royal Tern

Species of birds differ markedly from each other in susceptibility to organochlorines. The royal tern is an example of a relatively insensitive species. Although it lives in the same area of South Carolina as the brown pelican, it showed no evidence of eggshell thinning or lowered reproductive success. Residue levels of organochlorine pollutants in the tern eggs were similar to those in pelican eggs. The royal tern breeds for the first time when it is three or more years of age and usually lays only one egg per clutch. It is a long-lived species and its reproductive success is very good in South Carolina. Pollution effects have been suspected among other species of terns, however. Hays and Risebrough (1972) found abnormalities in several species of young terns near

Long Island, N.Y. These abnormalities seemed related to the very high load of PCBs they were carrying. Only a few dozen of the thousands of tern young seemed affected by the abnormalities. In the Netherlands, heavy pollution by certain organochlorine insecticides resulted in the virtual elimination of Sandwich terns (Koeman et al., 1967).

Estuarine Waders

The nesting colonies of herons and ibises found near the nation's estuaries are typically aggregations of several species, which vary with local habitat conditions. Greatest diversity is in the Southeast, where 10 or more of these species may nest together in a single heronry, accompanied by wood storks, double-crested cormorants, anhingas, and perhaps also brown pelicans.

Shell thickness of eggs of great blue herons, green herons, great egrets, snowy egrets, and black-crowned night herons has significantly decreased in some coastal areas since the mid-1940's (Anderson and Hickey, 1972; Faber et al., 1972; Faber and Hickey, 1973).

Reproductive success of a colony of great egrets in California declined between 1967 and 1970 (Faber et al., 1972). Successful nesting attempts decreased from 52 to 28 percent, and nests losing eggs increased from 30 to 54 percent. However, reproductive success of great blue herons in this colony did not decline during the same period. Egrets in the California colony were observed tossing broken eggs from their nests, a behavior that at least partially explains the disappearance of eggs during incubation. Grey herons in England also have been observed tossing eggs from their nests (Milstein et al., 1970; Prestt, 1970).

Thickness of the eggshells of the California egrets was 15.2 percent less than that of eggshells in museum collections (Faber et al., 1972). Thickness of great blue heron eggshells was 10.4 percent less than those collected prior to 1947.

In 1972, extensive field studies were begun of waders in the estuaries of the gulf and Atlantic coasts as well as freshwater habitats throughout the eastern United States. Both species and geographic differences in pollutant residues were apparent. Of samples analyzed thus far, great egret eggs or black-crowned night heron eggs contained the highest average amounts of DDE and PCBs at all localities where they were collected. Eggs of cattle egrets and glossy ibis generally had greater amounts of dieldrin than did the eggs of other species.

Dissimilar food preferences may be at least a partial cause of differences in organochlorine residues in different species. Great egrets and night herons

FIGURE 9.—Black-crowned night heron eggs were collected at 21 localities in estuarine and inland water areas in 1972 and 1973. Organochlorine residues are shown in Figures 10 and 11.

feed on larger fish of different kinds than do other birds (Bent, 1922, 1926; Palmer, 1962). Night herons are particularly active at dawn and dusk, whereas the other species feed more actively during the day. Cattle egrets and glossy ibis feed more extensively on lower invertebrates. Cattle egrets feed almost altogether in terrestrial sites whereas ibises feed exclusively in mud flats. Other species feed primarily in aquatic areas, eating a variety of organisms including fish of various sizes.

Differences related to geographic location proved to be greater than those related to the species. Both kinds and quantities of residues in eggs varied geographically. Distribution of residues in black-crowned night heron eggs is illustrative. Black-crowned night herons are one of the most widely located species of waders. They have declined both in Michigan and southern New England (Wallace, 1969; Hickey, 1969; Anonymous, 1971, 1973; Arbib, 1972).

Chemical residues were relatively higher in black-crowned night heron eggs from northern Atlantic estuaries (Fig. 9, 10, 11) than from gulf and southern Atlantic estuaries. Only mirex occurred more frequently and in greater amounts in the samples from the south. Residues were consistently highest in areas where the population had declined.

A black-crowned night heron egg from Long Island contained the greatest amount of DDE (61 ppm

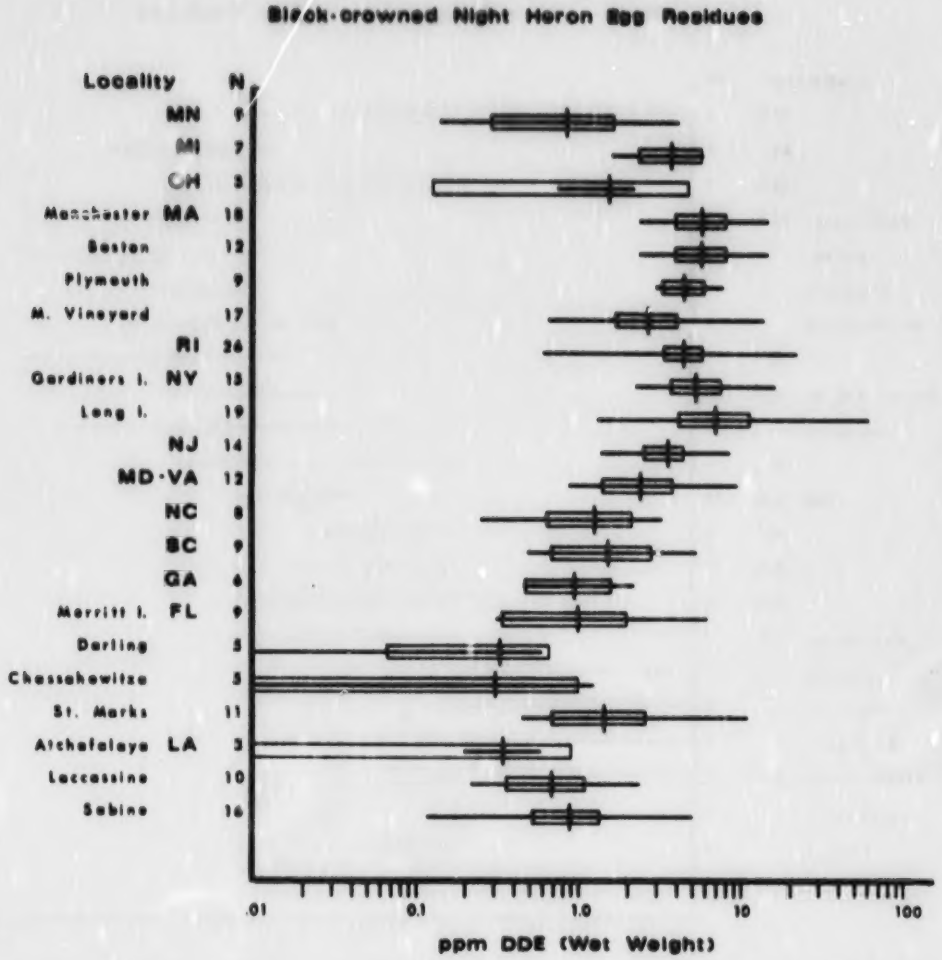

FIGURE 10.—DDE in black-crowned night heron eggs. Concentrations were highest in the northeastern estuaries. Vertical lines show the average values; enclosed bars show the limits within which 95 percent of the values are estimated to lie; horizontal lines show the complete range of values, from low to high. Residues were consistently highest in areas where populations have declined.

fresh wet weight). DDE exceeded 15 ppm only in samples from Long Island and Rhode Island. DDT concentrations generally were below 1 ppm, but measured 58 ppm in one egg from Long Island. The highest level of dieldrin in a single egg was 7.8 ppm in a sample from Plymouth Bay, Mass.; the mean for that clutch was 6.7 ppm. Dieldrin exceeded 2 ppm in samples from Martha's Vineyard, Mass., Rhode Island, and Long Island. Mirex (3.0 ppm) was highest in a sample from South Carolina; it exceeded 1 ppm in two other eggs from this locality. Hexachlorobenzene was measurable in samples from Chappaquiddick, Mass. (the maximum, 0.48 ppm), Manchester, Mass., Long Island, and western Lake Erie. The highest level of PCBs in a single egg was 102 ppm in a sample from Rhode Island, and the highest average level in a clutch was 94 ppm in samples from Boston Harbor. PCBs exceeded 25 ppm in samples from Manchester, Boston Harbor, Rhode Island, Long Island, and the Detroit River.

In six of the eight regions compared, shell thickness was significantly less in the 1972–3 samples than in samples taken before the mid 1940's. The greatest decrease has been in New Jersey (10.6 percent), Massachusetts (9.3 percent), and in New York, Rhode Island, and Connecticut combined (7.1 percent). The decline in eggshell thickness was significantly related to DDE contained in the eggs (Fig. 12).

Patterns of chemical residue distribution are diffi-

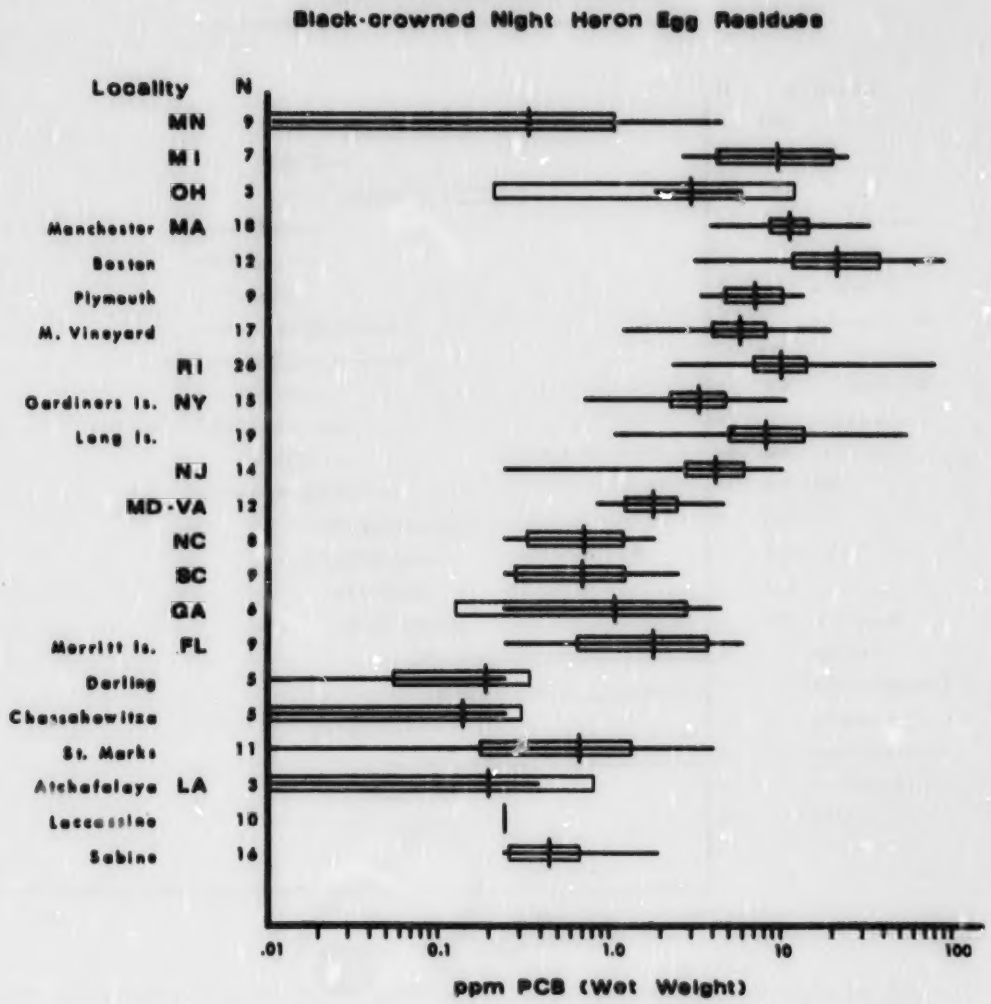

FIGURE 11.—PCBs in black-crowned night heron eggs. Concentrations were highest in the northeastern states, following the same pattern as DDE.

cult to interpret because migratory birds that nest in a particular locality may have over-wintered in dissimilar areas. Also, some herons move northward after the nesting season, prior to migrating southward. Some, however, remain along the Atlantic coast throughout the year, as far north as Maine.

It has frequently been suggested that the greatest pollution problems are in Latin America. The relationship of residues of organochlorines in eggs to wintering areas was established by examination of all available recovery records of black-crowned night herons that had been banded as nestlings in eastern North America. The records showed that fewer of the birds from the northern coast, where residues were higher, were recovered in Latin American countries, showing that the higher residues in northern birds should not be attributed to wintering in Latin America (Table 3).

CONCLUSIONS

Bird populations should increase with the reduction of estuarine pollution. Improved conditions of habitat and food supply will require reduction of both chemical and non-chemical pollution. Improved survival and reproduction will require reduction of organochlorine chemicals. Elimination of lead poi-

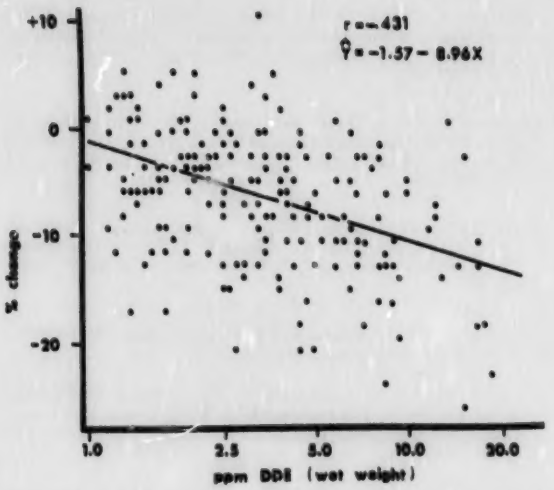

FIGURE 12.—Association of DDE residues in black-crowned night heron eggs with changes in shell thickness. Percentage decrease in shell thickness relates to eggs collected prior to DDT use.

Table 3.—Wintering localities of black-crowned night herons that nest along Atlantic estuaries. Birds that nest in the north and have high residues in their eggs are recovered less frequently in Latin America, showing that the high residues should not be attributed to wintering in Latin America.

Location of banding	Location of Recovery		
	U.S.—Canada	Latin America	Total
North Atlantic States[1]	147	13	160
South Atlantic States[2]	41	10[3]	51
Total	188	23	211

[1] New York to Massachusetts
[2] Florida to New Jersey
[3] Significantly greater ($P = 2.29$) numbers than from birds banded in northern Atlantic states.

soning of waterfowl will require the substitution of some less toxic metal, such as iron, in the manufacture of shot-gun pellets. The ecological impact of most heavy metals on estuarine birds is unknown.

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ESTUARINE LAND USE MANAGEMENT: THE RELATIONSHIP OF AESTHETIC VALUE TO ENVIRONMENTAL QUALITY

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ABSTRACT

Although advances in identification and management of aesthetic resources have been made possible through recent legislation and administrative guidelines dealing with the estuarine environment, new measures are needed if significant impacts on aesthetic resources and resulting effects on water quality are to be avoided. This paper recommends the adoption of expanded review responsibilities and standards on the part of federal and state agencies, and the creation of new funding elements to achieve improved estuarine aesthetic resource protection and management.

INTRODUCTION

Aesthetics has always been a hard word and difficult concept for government. Until recently, scenic or aesthetic resource protection often was more notable by its absence than by its inclusion in legislation or administrative actions dealing with critical coastal or estuarine concerns. The reasons for this are generally four-fold:

1) *unfamiliarity* on the part of agency officials and planners with the subject of aesthetics;
2) a traditional *bias* in systems-oriented planning and engineering disciplines against aesthetic considerations and values as "soft" or "subjective" areas in contrast to such "hard" and "objective" areas as economic, biological, water quality, and other factors more easily examined by empirical, systematic, and quantitative methods;
3) a *preference* on the part of protection-conscious planners and legislators to achieve aesthetic protection under the guise of supposedly more legitimate objectives as recreation, ecological protection, shore cover retention, and public safety (as in flood plain and erosion zone prohibitions).
4) a *slowness* of the courts to support government actions to protect resources on aesthetic grounds alone.

As Cerny has pointed out (1974), the bulk of case law on aesthetics has been founded on the urban experience. Little has come from litigation dealing with non-urban resources, although the latter of course has been the subject of considerable attention in terms of health, hazard, and resource utilization.

The courts have often held aesthetics to be a secondary or peripheral issue, while recognizing health and safety as primary constitutional concerns (Cerny, 1974). More recently, however, aesthetics has been recognized as an economic consideration, as in United Advertising Corporation v. Metuchen which found that "a discordant sight is as hard an economic fact as an annoying odor or sound."[1] In the noted case of Berman v. Parker the Supreme Court upheld the use of the power of eminent domain to achieve a more attractive community, stating that: "The concept of the public welfare is broad and inclusive. The values it represents are spiritual as well as physical, aesthetic as well as monetary."[2]

In the future, hopefully, the courts should be expected to increasingly support the recognition of aesthetics as a primary issue under the public welfare clause of the constitution. If this happens, government at all levels will be able to better regulate the appearance of natural and manmade resources in estuaries and their uplands. Government, however, must take the initiative in creating new legislation and administrative procedures to face the test of the courts.

Now that full and open consideration of aesthetic resources in the coastal zone has been legitimatized by the Coastal Zone Management Act of 1972, the lexicon of aesthetic resource management should soon become more familiar to officials, planners and the public. Bias against aesthetic value determinations should disappear, as criteria, standards, and

[1] 42 N.J. 1, 198 A.2d 447 (1964)
[2] 348 U.S. 26, 99 L.Ed. 27, 75 S.Ct. 98 (1954)

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methods for accomplishing them come into accepted use. Aesthetic resource protection and management will surely become recognized by the courts independent of, although reinforced with, other legitimate coastal zone concerns.

It is the intent of this paper, however, to demonstrate that new approaches and measures may be needed to ensure timely and effective achievement of public aesthetic objectives in the coastal zone.

Before proceeding further, a review of several pertinent definitions will help place the discussion in proper focus. The estuarine zone, with which we are directly concerned here, is defined under Section 104(n)(4), of the Water Quality Pollution Control Act Amendments of 1972 as an "environmental system consisting of an estuary and those transition areas which are consistently influenced or affected by water from an estuary such as, but not limited to salt marshes, coastal or intertidal areas, bays, harbors . . .." Although the terms "transition areas" and "coastal . . . areas" may be broadly interpreted as extending considerable distances into adjacent upland, it is unlikely that "estuarine zone" under the present writing of the Act can be interpreted to extend to the full view of estuary-related aesthetic resources, that is, to inland coastal zone horizons removed from consistent influence by estuarine waters.

The coastal zone, as defined under Section 304(a) of the Coastal Zone Management Act can be considered a more extensive entity, comprising coastal waters and adjacent shorelands "strongly influenced by each other and in proximity to the shorelines." The zone "extends inland from the shorelines only to the extent necessary to control shorelands, the uses of which have a direct and significant impact on coastal waters." Under this definition, virtually all coastal watersheds may be included, on the premise that runoff and water-borne pollutants and suspended materials influence coastal waters. In many instances, coastal watershed divides also effectively define the limits of aesthetic resources associated with the coastal zone, although other topographic boundaries are often needed to delineate them.

Estuarine zone aesthetic resources are features of estuaries and coastal lands which possess attention-arresting perceivable values. Intangible attributes may also be apparent and often strengthen the value of the resource. For example, common knowledge that marshes are essential to the estuarine food web and that they are endangered by man's activities adds to the aesthetic esteem in which marshes are held by the observer. Negative aesthetic factors are elements which diminish the landscape value of these resources: debris which mars a water surface, land fill encroachment which disrupts the visual integrity of a foreshore, or waterfront high-rise buildings which are architecturally styled without recognition of the inherent qualities of the estuarine zone within which they are placed.

Landscape management is a broad term which may be used to correlate four interdependent activities affecting estuarine or coastal zone aesthetic resources:

1) land use planning, including capability and area use priorities;
2) site selection for development or conservation purposes;
3) site planning of land modifications or facility development;
4) architectural and landscape design.

Each of the above four categories relates significantly to the wise management, protection, and use of the estuarine and coastal landscape.

Resource priorities are the best purposes to which land and water resources may be put under the wisest use principle. The full range of terms is employed in the Coastal Zone Management Act: preservation, protection, restoration, enhancement, utilization, and development.

One hitherto under-recognized fact is that aesthetic resources, under the definitions reviewed here, pertain to all observable manifestations of estuarine or coastal physical resources, not simply to "scenic" resources alone. The shift from scenic protection to aesthetic management implies a greater concern for the common or ordinary landscape, with which most people are in contact most of the time. Moreover, with the call for standards and criteria under both the new federal legislation and growing state legislation, emphasis is increasingly on the need for aesthetic protection, maintenance, or enhancement in all actions. Whether a physical resource is altered for conservation-education activity, for dense residential-marina development, or for large-scale facility construction, the same principle emerges: maximum maintenance or protection of appearance quality, i.e. safeguards even with development. The same principle is intended for already altered or degraded resource areas; restoration and enhancement planning is specifically called for in the CZMA, as is attention to potential, as well as existing coastal zone resources.

AESTHETIC RESOURCES AND THE FACTORS WHICH AFFECT THEM

The aesthetic resource problem in the estuarine or coastal zone is two-fold:

a) identifying and evaluating valuable aesthetic

resources and deciding what may be done to maximize their preservation and wisest use,

b) identifying negative aesthetic factors and what may be done to restore the landscape-waterscape to its fullest aesthetic potential.

The Aesthetic Resource Base

Figure 1 presents a condensed analysis of four aesthetic resources of the estuarine zone, selected attributes, and managerial and institutional implications. It should be stressed that aesthetic resources can be more accurately understood as aesthetic attributes of all perceivable resources. The following selected resource descriptions will demonstrate this.

Open waters, offshore and estuarine, have important aesthetic attributes. Ocean and other offshore waters possess dramatic aesthetic value where a sea-sky horizon can be perceived without interruption. Broad estuarine waters share some aesthetic qualities with offshore waters. Natural islands falling within view may enhance the overall aesthetic, creating even greater visual drama, but artifical islands, offshore platforms, dredging and drill ships, and other point elements may diminish this view, in proportion to their randomness and proximity to shore.

Estuarine foreshores and related edges possess many unique and uncommon visual characteristics. The "sea-of-grain" qualities of broad marshes of salt-marsh cordgrass or sawgrass and the flickering of breezes across the high marsh grasses are well-known features to even distant passers-by. Visual microcosms are also of aesthetic importance to both serious and casual students of the marsh: the rushing of a tide through a narrow inlet, or the fishing of waterfowl for crustaceans, the nesting and feeding characteristics of all marsh wildlife.

Nevertheless, attitudes toward marsh aesthetics, as toward all estuarine aesthetic resources, vary considerably according to place of residence, occupation, income, recreational preferences, age, education, sympathy with the conservation ethic, and even the day of the week or season—in short, on all the socio-economic and cultural factors that help determine attitudes and preferences of people towards all environmental values. Standing opposite each other, to see it simply, are the foreshore developer and the estuary preservationist. All others may stand somewhere between these two poles.

Analysis of these individual preferences, however, will not necessarily contribute to a firmer understanding of actions needed in the estuarine or coastal zone. Aside from the difficulty experienced by researchers to date in assessing public opinion about aesthetic values, the fact that preferences vary frequently according to all these conditions makes their validity problematic as a base for public long-term land and water resource use policy.

Furthermore, in light of the new status of all aesthetics in the coastal zone, the ordinary landscape will require careful attention along with the outstanding scenic assets or issue areas. The ordinary landscape will seldom be ranked high in preference analysis, yet it is the landscape which is most frequented by people, and where many of their aesthetic and recreational interests and satisfactions are being met. With time and the greater concentration of population in the coastal zone, the ordinary landscape will become increasingly important.

Problems and Impact Factors

General Conflicts Between Natural Resource Aesthetics and Development

A careful distinction must be made between design quality and aesthetic compatability of man-made modifications of land and water resources. A modification of the terrain (e.g. a power plant, a marina, a new town) may achieve a high degree of design quality when examined independently of the surrounding environment, but may fail to achieve aesthetic compatibility with the environment in one or more ways. The development may have been sited poorly in relation to the water's edge or to scenic background—instances of visual incompatibilities. Or the development may have intruded into the last remaining unaltered reach of a coastline—an example which depicts incompatibility with visual as well as intangible aesthetic resources (the latter including the interest in wilderness or rurality and a respite from the urban environment). Aesthetic compatibility, is high, obviously, when incompatibilities are avoided, either wholly, or to the maximum degree. The term aesthetic resource protection can be said to mean the minimization or prevention of aesthetic imcompatibilities.

To a degree, therefore, aesthetic resource protection can be considered a preservationist mechanism. The Wild and Scenic Rivers Act is one example of legislation to prevent incompatible alterations to the nation's aesthetic resources. But aesthetic resource protection is not exclusively an instrument for preservation. Employed in a management sense, protection of the environment against aesthetic incompatibilites can be operative at every level of activity between preservation and intensive de-

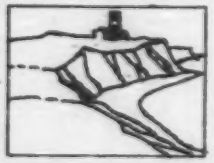
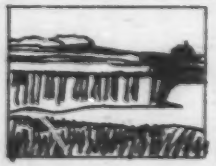
	Resource Type	(Selected) Visual Attribute(s)	(Selected) Intangible Attribute(s)	Managerial Implications	Institutional Implications
	beach	-sand qualities -forms -sweep	-molding by sea energy -primordial state, geological record	-exclusion or regulation of structures -debris, trash, dune buggy regulation -user-capacity determinations	-town exclusionary use vs. open public use (visual access) -public use of private beaches -maintenance funding
	riverbank	-landform configuration -vegetative characteristics -space/closure patterns	-order given to rural and urban land use -natural corridor provides physcho-logical linkage to both source region and sea	-bank erosion protection -vegetative edge protection -clearance and planting management -urban area rehabilitation	-conciliation of split jurisdictions over riverbank areas -administration of public access and access acquisition
	bluff	-landform face -crest patterns -height	-impressiveness -sense of geo-logical process -sense of hazard	-exclusion or regu-lation of use on or near crest and face -cautionary use of erosion protection measures	-development of legislative and administrative regulation of bluff areas
	tidal marsh	-vegetative infrastructures -seasonal change -wind imprints -tidal changes	-sense of (urban) endangerment -sense of sig-nificance in estuarine eco-system	-prohibition of dredging, filling -regulation of permitted, compatible use	-development of legislative and administrative regulation of marsh areas

FIGURE 1.—Selected aesthetic resource and problem definitions.

velopment. In practice, aesthetic resource management has often been meshed with other environmental management considerations, from public policies and guidelines for land use and development decisions to state land use zoning (e.g. Hawaii), shoreland zoning ordinances (e.g. Wisconsin, Minnesota), shoreline appearance and design regulations (e.g. California), and strong land-use controls (e.g. Vermont, Maine).

With the above background distinctions in mind, the following conflicts should be recognized as being of prime importance in the coastal or estuarine environment.

RESIDENTIAL DEVELOPMENT

Population growth, adequate disposable incomes, increased interest in water-related recreation, and in seasonal or second-home acquisition have resulted in enormous pressures for waterfront residential development in estuarine zones of the United States. In Florida, and elsewhere, marshes and intertidal flats have been dredged and filled to create finger canal communities, resulting in severe damage to estuarine ecosystems, as well as significant aesthetic impact.

In other areas of the estuarine or coastal zone densely set seasonal homes with insufficient sideyards block views to the water and present walls of monotony. Condominium, multiple unit, and cluster development typically achieve better standards of design and improved site layout than row development or tract housing, but also elevate densities and the impression of intrusion to suburban or near-urban levels. In most cases public access to beach, bluff, or water edges is precluded or greatly diminished with a concomitant reduction in the public enjoyment or utilization of these aesthetic resources.

Bluff-top development often diminishes shoreline aesthetic value, since user desires to view water and shoreline from the bluff are frustrated, as may be the desires of users below the bluff or across the water to view natural scenic heights and skyline.

Development on sand dunes, interdunal areas, and barrier beaches seriously reduces the aesthetic value of beach and dune resources for even distant users, since one key aesthetic criterion of such systems is the magnitude of their uninterrupted "sweep" away towards the long-shore horizon. The unique geometry of windformed dunes is also lost under development. The general answers to all land and water use problems are two-fold: greater exercise of powers to prevent the siting of development in sensitive estuarine areas, and greater exercise of powers to secure appropriate siting and design within the overall site.

MARINA DEVELOPMENT

The aesthetic impacts of boating facilities in estuarine zones are complicated. On the one hand, most boats are of great aesthetic interest, since they constitute functional design responses to the challenges of moving on water. They are also generally colorful, sometimes powerful, and always part of a fascinating tradition that began with two of mankind's earliest livelihoods: fishing and navigation.

On the other hand, the congestion in large marinas, exposed repair and storage structures, and parking areas may constitute negative aesthetic factors to many people, including boaters. The preemption of marshes or of water surfaces and shorelines in small estuarine areas may also damage the aesthetic value of such areas in the view of conservation-interested users. Outboard engine noise has also been considered offensive by many. Certain recreational conflicts, such as that between power and sail users, can also be considered an aesthetic concern.

COMMERCIAL PORTS AND MINERAL EXTRACTION

Commercial navigation and ports also create mixed aesthetic impacts. Ships and dock facilities arouse the interest of most people. Yet the total image of ports and port-related industry to users in the distance may not impart a sense of high aesthetic value. Very large crude carriers (VLCC's, or "supertankers") may be impressive as a design aesthetic, but viewing them may also trigger negative intangible reactions related to anticipations of possible collisions and oil spills.

Most port areas also have large warehousing, open depot, and sprawled service and equipment storage facilities which possess little of the interest that characterizes the ships and docksides. Floating debris, polluted water, deteriorated wooden piers, blighted waterfront commercial buildings, and unattractive land uses that are unrelated to the water (e.g. scrapyards, utilities, parking lots) also are present in many port-industrial waterfronts.

Mineral extraction presents an aesthetic concern to the extent that this activity exposes structures and activities to view along non-industrial shores. The present direction of Outer Continental Shelf and shore-area oil exploration, extraction, transfer, and processing may create intense conflicts with estuarine aesthetic resources if caution is not exercised in preventing undesirable offshore or onshore patterns along scenic coasts.

URBAN CENTERS

High-rise urban development may introduce into estuarine zones and coastal areas a number of aesthetic effects other than those originating in density and land usage as such. Height, the principal visual attribute, can be perceived by the viewer as a dominance of the structure over the surrounding landscape. The higher the building, the greater the dominance, generally. Impact may be modified by such factors as proximity to (or setback from) the shoreline or other vital user locations, degree of urbanization of the surrounding landscape, elevation of the site above surrounding terrain, building mass and exterior architecture, color, texture, and reflectivity of exterior materials, and masking vegetation and landforms. In shore areas of particularly important scenic value, it is generally necessary to exclude all prominent buildings or to keep the tops of buildings close to or within the vegetational canopy if dimunition of the existing aesthetic value is to be avoided.

Adverse community reaction to planned or completed high-rise projects on coastal margins can be interpreted to be largely an expression of opposition to the anticipated dominance of the project over the landscape, as well as to the presumed preemption of public view-space by a small group of privileged users. The subordination of the Hudson River Palisades by high-rise apartment construction has prompted public reaction on both accounts. The unsuccessful 1972 San Francisco referendum bid to bring a halt to further high-rise construction is another example of strong public concern on this issue.

PUBLIC ACCESS AND RECREATIONAL SHORELINES

The fact that recreational shoreline is severely limited indicates the lack of satisfaction many coastal zone or estuarine users presumably feel as they seek out viewing or recreational access to the water. Public viewing points on coastal and estuarine shores are in short supply, while private ownership and development mask many scenic vistas and other aesthetic resources.

Public shoreline recreational facilities resolve the lack of access, but may be afflicted with congestion by numbers of people that exceed the capacity of the resource to support them. Moreover, as the Outdoor Recreation Resources Review Commission ably pointed out in 1962, the demand for beach and other shore recreation facilities is highest in proximity to urban centers, where supply is most often lowest. An indication of the intensity of the demand for coastal and estuarine access opportunities is the growth in the numbers of saltwater anglers in the U.S., up from approximately 8.3 million in 1965 to 9.5 million in 1970 and projected to as high as 29 million in the year 2000 (Deuel, 1973).

All of the above described recreational access interests also possess aesthetic implications, in terms of the visual quality of access points and appurtenant facilities, of actual or potential user congestion, or of the land usage barriers which block effective access.

UTILITIES

Power plants, because of their physical size, industrial appearance and unattractive edge qualities (e.g., high fencing, oil tanks, coal stockpiles, and equipment depots) are often aesthetically displeasing to large numbers of people. In the case of nuclear power facilities, safety questions can also be presumed to adversely affect community attitudes concerning aesthetic fitness, apart from stimulating opposition on the grounds of hazard alone. In many cases, cooling towers and their condensate plumes have been identified as negative aesthetic factors, as have been dredge and fill activities associated with site development or cooling water processes.

LAND AND AIR TRANSPORTATION

Highways, railroads, bridges, causeways, and parking facilities have major aesthetic impacts upon estuarine/coastal zones because of their size, linear encompassment or traversement of horizon or open areas, and vehicular effects (noise, motion, and exhaust fumes).

Some of these impacts may be benign, if not beneficial: a well-designed bridge span over a river mouth, for example. But many other instances are often judged detrimental, particularly where new facilities are introduced into sensitive or vital estuarine areas in a natural state.

Public transportation to shore points is an underutilized alternative which may offer important answers in the future in decreasing vehicular congestion, suburban sprawl, and related impacts in estuarine uplands.

Airports likewise have mixed aesthetic effects. Jet take-offs and general aircraft activity may be visually exciting, even spectacular to the observer. On the other hand, the airport itself may appear visually dull to the observer from an opposite shore, or on the land side of the facility. Aircraft noise and jet exhausts, airport structure visual qualities, and

airport expansion on filled marshes or mudflats may also elicit strong negative visual or intangible responses.

MANAGERIAL IMPLICATIONS

The resource and impact definitions discussed above suggest a summary of related managerial issues as follows:

1) Aesthetic resources and values of estuarine and coastal zones have not been well understood or systematically evaluated by the professional or by the public as a whole.

2) Planning tools for surveying, inventorying, and evaluating estuarine/coastal aesthetic resources need to be more carefully explored and used. Direction and guidance for these are needed from federal and state agencies with responsibilities for coastal/estuarine management.

3) Aesthetic resources and values may be perceivable (visual, auditory, or olfactory) or intangible. The latter is essentially an observer response to social, cultural, economic, or physical factors which affect his or her conceptualization of the resources or values concerned.

4) Important aesthetic resources of the estuarine/coastal zone include some that are specific and unique to vital or critical areas and some that are common or ordinary within either the estuarine or upland landscapes. The intangible or psychological importance of the estuarine/coastal zone elevates both beneficial or adverse aesthetic effects to a level of significance.

5) Impacts may be effects on specific aesthetic resources (e.g. a power plant marring a scenic vista) or effects on the general estuarine resource (e.g. a power plant not marring any horizon or foreground, but objectionable on the basis of the project design's effect on the overall aesthetic value of the estuary).

6) The magnitude of an aesthetic impact and whether it can be considered negative or beneficial or both will depend largely on the degree to which the observed area is urbanized—or conversely, retained in a natural state.

7) Even within highly modified or urbanized areas, however, objects or activities which are aesthetically displeasing may still not be exempted from observer disapproval.

8) Aesthetic incompatibilities may be a) endemic, i.e., spread throughout the estuarine/coastal region, much as unregulated second-home and recreational-seasonal housing spread; b) intrusive, i.e., created by the introduction of non-"fitting" developments into local or specific resources; c) site abusive, i.e., displaying poor site planning; and d) sub-standard design, i.e., in which development is characterized by poor architectural design quality.

9) Although some aesthetic regulation has been validated by court test cases, other questions of constitutionality have not yet been resolved.

10) Permit and project review systems have not absolutely prevented development in coastal/estuarine zones. Whether the institutions responsible for administering these systems will allow large aggregate development will only be known in time and in light of political power adjustments.

Recommendations for improved estuarine zone landscape management outlined below will be addressed to the above-defined problems.

PREVIOUS AND CURRENT GOVERNMENT PROGRAMS

To date, a number of key federal and state programs have established important measures or frameworks for dealing with the estuarine and coastal landscape.

Federal Programs

The Water Resource Planning Act of 1965 provided for consideration of aesthetic factors in comprehensive water and related land resource planning. Principles and Standards issued by the Water Resources Council (1973) under the Act detailed a number of criteria for weighing aesthetic values but did not provide guidance on appearance and design of facilities in resource areas that are marked for development or on restoration and enhancement questions.

The National Environmental Policy Act of 1969 provided for the identification and consideration of aesthetic values that might be beneficially or adversely affected by actions undertaken by or under the aegis of the Federal government. The requirements for identification and evaluation of both direct and indirect effects of the proposed action, for consideration of measures that might mitigate adverse effects, and for weighing all feasible alternatives provide an incentive to project planners to exercise greater care for aesthetic values in early planning stages and a lever for adjustment under public criticism in the post-planning stages. NEPA, however, does not provide for set criteria or standards that would predetermine project site selection, planning, or design. Each project is evaluated on a case by case basis.

The Coastal Zone Management Act of 1972

expressed "a national interest in the effective management, beneficial use, protection, and development of the coastal zone." The coastal states are encouraged and assisted to define and to propose means of control over permissible land and water uses in the coastal zone and to give full consideration to aesthetic as well as other values in the development and implementation of management programs. The Office of Coastal Zone Management, in the National Oceanic and Atmospheric Administration, is expected to see that state Section 305 management plans contain unified policies, criteria, standards, methods, and processes that are adequate to deal with "land and water use decisions of more than local significance" prior to continuing CZMA grant assistance.

Under the Act, and with the guidance of OCZM, constructive and specific new actions may be anticipated on the part of the states to acquire and regulate land and water resources of aesthetic importance. Appearance and design regulations, permit procedures, comprehensive planning, and protective local and state zoning will play important roles. The CZMA, however, is permissive in nature, and will be effective in improving individual states' policies towards aesthetic resource management only to the degree that the states are willing to adopt new measures within their political and legislative systems.

The CZMA provision, under Section 306(c)(8), for adequate consideration of the "national interest" in the siting of facilities "other than local in nature" was included in the Act ostensibly to satisfy misgivings of the electric power industry. But the fortunate ambiguity of this clause should offer an opportunity for subjecting all large-scale facilities that are proposed for coastal zone locations to all the site selection, site planning, and design criteria encouraged by the Act, rather than exempting such facilities from them. Which direction will be taken will be seen only with time.

Section 306 administrative grants to the coastal states will, of course, be central to the effectiveness of the Act. It may be predicted that a large part of Section 306 funds will be used for acquisition purposes, but it can only be speculated how much will be earmarked for "restoration and enhancement" purposes. Acquisition (fee title or scenic/access easements) of presently undeveloped scenic areas is vitally necessary, but restoration and enhancement efforts are in many areas no less urgent, particularly where ill-planned development has already adversely affected aesthetic values.

Another weakness of the Act is its omission of directives to specifically consider multiple-use of resources in the coastal zone, a concern recommended by the Commission on Marine Science, Engineering and Resources (the Stratton Commission) in 1970. Because of this omission, it may be difficult to encourage large-scale facility or large private developers to provide for scenic-aesthetic or recreational access joint objectives.

The Federal Water Pollution Control Act of 1972 provides for potential beneficial aesthetic impact on estuarine waters. Many of the quality standards required by the Act (relative to color, turbidity, floating solids, debris, oil film, odor) are in essence aesthetic quality standards and are at least as great a matter of concern to the public as the Act's strictly biological and safety standards.

To secure desired water quality objectives, the Act and its 1972 Amendments provide for a number of measures designed to affect land use management, particularly under Section 208 of the Act. The level of future growth that an area can accept and land use densities may thus be adjusted, at least in theory, with consequent possible aesthetic benefits.

Under the Act, the Corps of Engineers is required to apply EPA criteria in the disposal of dredge spoil in navigable waters. Although adverse aesthetic impacts might be avoided indirectly by this requirement, there is no direct attempt to guide the Corps on aesthetic resource protection related to spoil disposal.

Section 201(f) of the Act provides for multiple use for open space and recreational purposes of lands and easements acquired for waste treatment facilities and sewers. However, the selection of flood plains or foreshores is not specifically excluded under the Act; the aesthetic impact of utility construction in such resource areas can be considerable.

The Fish and Wildlife Coordination Act of 1934, as amended, provides the basis for comment to the Corps of Engineers on project permit applications, by the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the state in which the project is funded. The Fish and Wildlife Service issued guidelines in August 1974 to aid agency personnel in reviewing applications for Corps permits. Here too, consideration of aesthetic resource protection is indirect, at best, even though maintenance of high visual quality in marsh and estuarine environments can be considered significant to the satisfactions of angler and hunter.

The Housing and Urban Community Development Act of 1974 will provide block grants to states and communities for community and regional planning and development purposes. No specific guidelines, criteria, or standards for waterfront development, rehabilitation, restoration, or enhancement are provided. The Act, as has the Housing Act since its initial passage, thus only weakly addresses the

need to distinguish development and redevelopment areas on estuarine zone and urban waterfront lands from other urban areas.

State Programs

Recent legislative and administrative actions taken by the coastal states relative to aesthetic resources and impacts are diverse and in many cases highly significant. Setback and frontage tree cover requirements are included in the shoreland zoning ordinances of Wisconsin and Minnesota. Appearance and design regulations are presently being developed by California and its six regional coastal zone conservation commissions. Washington's shoreline protection legislation provides for the development of county policies and regulations (Whatcom County Planning Commission, 1972). The state zoning of Hawaii and the strong land use control legislation of Vermont and Maine also are producing generally beneficial aesthetic impacts.

If the current programs of the coastal states were assessed, it would appear that there is a definite trend towards greater use of shoreline regulations, with an emphasis on permit and approval procedures, some emphasis on state-wide zoning, and little emphasis on acquisition.

Since all relevant federal legislation depends to one degree or another on state programs for effectuation, it may be observed that some states may meet or exceed expectations implicit in national legislation if this trend solidifies. On the other hand, permit and approval frameworks provide only partial, rather than absolute, protection to resource areas. The degree of effective area protection will depend on the degree to which permit applications are denied; even a low percentage of approvals can result in significant incremental urbanization of a presently natural area in time. The degree of effective site planning and design management, however, will be dependent on the degree to which permit approval conditions, building codes, zoning ordinances, and related tools are refined to reflect aesthetic resource protection needs, under any management system.

Both the CZMA and the anticipated national land use policy legislation, the former with regard to "areas of particular concern" and the latter with respect to "critical environmental areas," urge the states to adopt measures for the protection of unique areas, but there is no assurance that these will constitute large proportions of the estuarine/coastal zone, or that they will constitute preservation-priority areas rather than conservation-with-tolerable-development areas.

With regard to development within urban areas, little state legislation exists which provides more significant guidance on waterfront aesthetics than the minimal provisions of the Housing and Urban Community Development Act.

RECOMMENDATIONS

The character of estuarine and coastal aesthetic resources, impact factors, planning and management requirements, and shortcomings of existing legislation point to the need for improvements in the following areas of estuarine landscape management concern:

Land Use Planning/Area Use Priorities

1) A national policy and program is needed for preservation of significant estuarine and coastal landscapes that express their highest aesthetic, cultural, or historic value in their present state and are not adequately protected under existing legislation. Where states have not adopted legislation to preserve or adequately conserve significant wetlands, bluffs, islands, beaches, headlands, and other important natural aesthetic resources, the Federal government should be empowered to consider direct action to protect them.

2) The EPA should develop detailed aesthetic criteria in review of discharge effects under the Pollutant Discharge Elimination System so that it can better respond to visible water quality parameters as well as invisible parameters which indirectly affect estuarine aesthetic quality.

3) Both the federal and state levels should be assigned specific responsibilities for aesthetic review in connection with the Corps of Engineers permit program, either under new amendment to the Fish and Wildlife Coordination Act, or under new legislation.

4) New legislation is needed to express the national interest in the protection and management of aesthetic resources on a par with the national interest in other resources such as water, air, and land. The new legislation should assign primary coordinating responsibility to a single lead federal agency. Serious consideration should be given to naming the National Park Service to this post with an appropriate new congressional mandate.

5) New policies and compensatory mechanisms are needed to enable states to retain whole areas at given levels of development or at no-growth. In some parts of some states, such areas may be regional in character. Although the difficulties are severe, the

needs exist, if a diversity in coastal landscapes is to be maintained.

Site Selection

1) Legislation governing the selection of sites for large-scale facilities should be amended to require specific consideration of alternate locations situated inland of all significant estuarine landscapes, particularly those which also possess important ecological or cultural characteristics.

2) Federal legislation governing estuarine sanctuaries should be amended to provide for the acquisition or other protection of estuarine as well as related upland areas of significant aesthetic, as well as scientific and educational, value.

3) Under the CZMA, states should institute conditional permitting based on site planning and design performance standards, for designated permissible uses.

Site Planning and Design

1) Federal legislation governing housing, urban, community, and rural development should be amended to require the adoption of guidelines, criteria, and standards for development, redevelopment, and rehabilitation of areas in proximity to waterfronts. Such legislative changes would relate to inland riverine as well as to estuarine zone lands. River corridor and estuarine zone boundaries should be delineated within existing jurisdictions, urban and non-urban, to demarcate the areas within which the waterfront related provisions would apply.

2) Substantial funding for waterfront related rehabilitation, as well as for restoration and enhancement of natural or semi-developed areas within the estuarine/coastal zone should be appropriated under government programs specifically earmarked for this purpose. Funding for these needs could be aggregated with HUCDA block grants and CZMA Section 306 administrative grants, but the need for significant action in rehabilitation, restoration, and enhancement points to the desirability of independent and earmarked program elements.

3) Provision should be made for further research, consideration, and adoption of landscape assessment, site planning, and design criteria and standards for the estuarine and coastal zone. Criteria and standards for the management of aesthetic resources which are of national interest should be granted highest priority in federal, federal-state, and local programs. Further research and development of methods for inventorying and evaluating aesthetic resources should also be conducted. Federal programs should guide the states more specifically in developing appearance and design guidelines, criteria, and standards to include variable setback and height controls (varied to relate to topography, shore configuration, and other aesthetic considerations), multiple-use concepts (use of utility and other facility edges), aesthetic zone priorities (adjustment of siting and design standards in relation to the intrinsic wildness or urbanization of a given resource area), and other concerns.

Federal and state authorities with jurisdiction over the siting and design of offshore structures and artificial islands should be encouraged through legislative amendment to develop suitable appearance standards for such facilities.

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RECREATION ACTIVITIES IN THE NATION'S ESTUARINE ZONE

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ABSTRACT

Determinants of recreation activity are discussed and justification for the provision of recreation services by the public sector outlined. After reviewing the availability of data and other studies pertaining to recreational use, projections of recreation demand are made for selected activities. Economic models based upon a 1972 national recreation survey serve as the basis for this effort. The implication of these forecasts for the nation's estuarine areas is evaluated and policy recommendations, based on this analysis, are provided.

INTRODUCTION

Significant portions of the nation's outdoor recreational activity are either water based or water related. The latest National Recreation Survey found that over 38 percent of total outdoor recreational hours in the summer of 1972 were spent participating in water related activities (see Table 1). As a result, recreation has become a major use of our nation's water resources.

A substantial portion of the water area available for recreation is encompassed by the estuarine zone. Moreover, the location of the zone in relation to major population centers has made it an increasingly valuable resource. Yet, 59 percent of the area, excluding Alaska, remains undeveloped and over 70 percent resides in private ownership. About 25 percent is currently used for recreation (U.S. Department of the Interior, 1973). This is one reason the nation's estuarine areas have become an important consideration for public policy. Preservation of undeveloped portions of this resource for future recreational use will require public action. The extent and mechanism for such action must be decided in the political arena.

But why public and not private action in allocating the use of a resource like our estuarine areas? A number of factors are involved. We will review only several of the principal features. First, because access to natural areas by the public is often difficult to control (at cost acceptable to a profit making enterprise), public provision and control may be required. Difficulty in extracting a price for the use of some areas like estuaries has often discouraged private sector action to develop or preserve. Second, because of the profit making motive, resource allocation by the private sector will often emphasize short term monetary returns at the expense of long run environmental or social considerations. Third, society's preferences with regard to considerations like environmental quality may not be profitable for the private sector to provide. Consequently, governments may be called upon to correct the situation.

However, when public action to correct private market failure means public provision, the self-balancing of supply and demand provided by the private market is largely lost. Price incentives are weakened and, as a result, information feedback to governmental decisionmakers is curtailed. Without information, public recreational programs may be no more responsive to social demands than the private market alternative.

As a consequence, if public intervention is to provide results which are socially more optimal than those obtained under conditions of non-intervention, public decisionmakers require an adequate information base and the appropriate utilization of that base for analytical purposes. Unfortunately, historical data relevant to the estuarine zone-recreation interface is almost nonexistent except for a few geographic areas. Consequently, any analysis of the problems and possibilities from a national viewpoint starts from a decided disadvantage. On the other hand, the literature on recreation economics has continued to develop a sound methodological framework for public policy analysis (Kalter, 1971) and the data base of national recreation statistics has continued to improve. From this background, important factors determining recreational activity, both in general and for specific areas like estuaries, can be adjudged. A discussion of these factors will be the initial task of this paper. Then, available

Table 1.—Percent of national recreation survey who participated, estimated total U.S. participation, average hours of participation, and estimated total hours of U.S. participation by water related activity in the summer quarter of 1972[1]

Activity	Percent of NRS respondents who participated	Estimated total U. S. participation (millions of act. days)
Other Swimming Outdoor (Non-Pool)	34	487.1*
Fishing	24	278.2*
Pool swimming	18	257.0*
Nature walks	17	148.9
Other boating	15	126.1
Water skiing	5	54.1
Canoeing	3	18.3
Sailing	3	32.5

Activity	Average hours of participation	Estimated total hours of U. S. participation[2] (millions of activity hours)
Other swimming outdoor (Non-Pool)	2.6	1,266.46
Fishing	4.4	1,224.08
Pool swimming	2.8	719.60
Nature walks	2.0	297.80
Other boating	2.8	353.08
Water skiing	2.6	140.66
Canoeing	2.3	42.09
Sailing	4.4	143.00
Total		4,186.77

*Statistically reliable within 10 percent.

[1] Excludes wildlife and bird photography, hunting, camping and other activities that may be water related.

[2] Total for all activities surveyed equaled 10,978.15 million activity hours.

Source: Adams, R. L., et al., Outdoor Recreation: Appendix "A", An Economic Analysis, U.S. Department of the Interior, December 1973.

empirical evidence will be used in an effort to evaluate the role of the nation's estuaries as a component of recreation supply, and the impact this role has on the economy.

DETERMINANTS OF RECREATION ACTIVITY

Actual recreational activity at any time is the result of interactions between consumer demand and available facilities. The resulting activity requires the participants to make outlays for associated expenses. This cost (or price) includes items like travel and lodging, as well as user fees at the recreation site. Unlike a private market situation, however, the resulting conditions may not imply market clearing in the case of publicly provided facilities. That is, some demand may not be satisfied (at a given quality level) even though consumers are willing to undertake the necessary costs. This stems from the lack of proper market signals and government response in adjusting the supply of public facilities.

These conditions are illustrated in Figure 1. Recreation demand, DD, exhibits the normal inverse relationship between price and quantity (all other factors taken as given). When recreation facilities are publicly provided and admission fees are administratively determined, however, the average price, P, to a group of participants can remain stable during any given period of time. Since supply is also publicly provided and the quantity available during a given period depends on budget considerations, the recreation supply function can be shown as inelastic with respect to price. Thus, if public information is accurate and budget decisions are responsive, market clearing can take place. The supply function SS reflects this somewhat fortuitous circumstance. On the other hand, if government planners have inaccurately analyzed the demand for facilities at P, or if budget processes do not permit investments in facilities to point S, then a situation like that shown by the dotted line S^1S^1 will result. With an administrated price of P, a facility shortfall of $S\text{-}S^1$ will occur. Conversely, an over supply could develop if facility supply is developed beyond S.

Demand

Recreation demand (the functional relationship between quantity desired and socioeconomic factors) is, for the most part, influenced by the same factors influencing the purchase or use of other goods and services. Thus, an individual's demand for recreation relates to the costs (monetary or others, such as time) incurred to participate, his tastes and preferences, his socioeconomic characteristics (which may affect preferences), and the availability and cost of alternative goods, services, or uses of fixed

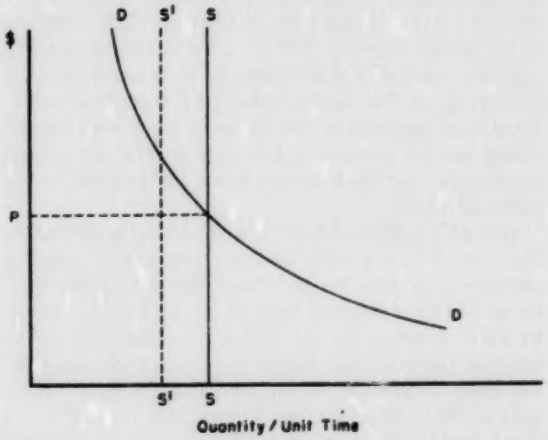

FIGURE 1.—Hypothetical recreation demand-supply relationships.

budgets (money, time and energy). Demand for a particular type of recreation or for a particular recreation facility depends on these factors as they relate to a given population and to the size of that population. In addition, quality factors will influence the shape of the demand function for specific sites and/or types of recreation.

Demand functions have been estimated, based on past experience, for individual recreation sites as well as for market areas. Functions derived with reference to specific locations have a variety of potential uses, such as developing and evaluating recreation expansion plans at the site (Clawson and Knetsch, 1966). They, however, do not usually provide adequate data for comprehensive recreation planning at the national or regional level. Account needs to be taken of overall market demand and the competition for that demand from alternative sites (Kalter and Gosse, 1969). As will be pointed out below, the question of alternatives may be critical in reviewing policy decisions relating to recreational use of estuaries.

Supply

Facility supply, or more broadly, recreation site capacity, is the balance wheel to the demand side of the recreation picture. It, however, is difficult to define in a manner consistent with normal measures of use. Whereas recreation use has traditionally been defined in terms of time (visitor days at a site or activity days of participation in a given type of recreation), capacity is basically the ability to accommodate participants. Thus, capacity can vary for a given site due to intensity of use. Moreover, since capacity cannot be stored for future use, we can only speak of instant capacities (the ability to accommodate use at a given moment in time). Thus, we often encounter the phenomena in recreation of having capacity deficiencies on weekends and holidays while maintaining extensive surplus facilities during the work week.

Of equal importance in measuring capacity are two other factors. First, the quality of a recreation experience offered by management of a given area can cause substantial variations in its capacity. For example, if one aspect of quality (crowding) is permitted to deteriorate, capacity of an area can be increased, though not necessarily at a linear rate. Although "quality" is a subjective factor determined by individual preferences, that will not be its use here. Rather, we seek to identify a set of characteristics which can be used to group sites into categories for analysis. Individuals may have different preferences among such a classification. Second, site capacity (at a given quality level) is related to the activity mix at the site. The existence and timing of complementary and competitive activities can affect the overall capacity of a site.

Thus, site capacity has been an elusive concept from a definitional point of view. From a public planning viewpoint, however, definitional problems translate to analytical problems. The need to provide a linkage between demand and supply (capacity) is basic to decisions concerning public investment in the quantity and quality of recreation-related facilities. Estimates of the value related to provision of additional capacity or of changes in the quality of existing capacity cannot be used in a benefit-cost decision framework without knowledge of the relationship between capacity provided and various levels of resource inputs.

Two techniques have been suggested and used for translating physical measures of area and facilities into economic capacity. First, physical standards have often been used by public agencies. Such standards identify the magnitude of physical areas and facilities needed to provide a recreation experience, at a given level of quality, for a given number of recreation or activity days. Because standards relate to average rather than marginal values, a preferred approach would take account of the non-linearities involved. Thus, the traditional production function has been suggested as a second means for relating capacity to the cost of resource inputs (land, labor, and capital). Empirically estimating such functions, however, suffers from the same definitional problems raised earlier and the additional practical problem of holding quality constant for estimation purposes. Progress in quantifying supply concepts, by either method mentioned, has not progressed as rapidly as work relating to demand.

Recreational activity and quality factors

The role of quality in determining recreational activity was only referred to briefly in the previous sections. The term "quality" is a subjective and somewhat elusive factor in the economic equation. It relates to both the concepts of supply and demand. The economist normally considers separate demand relationships relevant for each level of quality of a given product or service. The physical representation of quality, then, takes place on the supply side of the equation.

The physical characteristics relating to the quality of a water-based outdoor recreation site can be natural or manmade. Surroundings, facilities, intensity of site use, and water quality, itself, all are

characteristics which permit a subclassification of water-based recreation sites by quality. Each of these factors may, itself, be complex in makeup. For example, water quality is usually considered a composite of many factors (i.e., BOD (biochemical oxygen demand), nutrient levels, turbidity, et cetera). In addition, non-site quality factors can affect one's perception of the overall recreation experience.

Available studies

Studies of outdoor recreation demand relating to a given population area are relatively rare (Kalter and Gosse, 1969; Cicchetti, et al., 1969; Adams, et al., 1973). Unlike the demand for most goods and services, the demand for recreation is heavily dependent on transfer costs (costs of reaching and departing a recreation site) and is, thus, linked spatially with the site of purchase. The site has, therefore, become the natural focus for data collection and analysis. On the other hand, market or population oriented demand studies must be based on data collected from a sample of the entire relevant population, rather than those who visited certain (or even a sample of) recreational sites. Not only are such data collection efforts normally not directed at the immediate needs of a particular agency, they are expensive to carry out.

The dilemma is obvious. For most policy work at the national level, market oriented efforts are desirable. Yet they are empirically difficult and expensive. Moreover, the resulting specificity often turns out to be at a higher level of aggregation than desirable for some applications. It is precisely this problem which plagues analytical work regarding recreational demand for the nation's estuaries. Individual estuary areas may differ to the point where extrapolation from specific site oriented studies can lead to erroneous conclusions for national policy. Yet the market oriented studies which have been carried out do not permit the isolation of demand related specifically to estuarine areas nor show the trade-offs between these areas and alternative supply possibilities.

On the supply side, the data base is even thinner. Supply inventories have been conducted as part of previous national recreation surveys (ORRRC, 1962; U.S. Department of the Interior, 1973). The conceptual and definition problems discussed above, however, have made the data difficult to interpret in practice. In one instance the data has not even been compiled or released by the government (U.S. Department of the Interior, 1973). The principle involved is critical to formulating proper public policies since supply, as well as demand, data is needed if the trade-offs among alternatives are to be properly evaluated.

Because of the difficulties involved in quantifying quality factors, many analytical efforts have assumed away these issues. Since quality considerations relate to more than just the site itself, this has been an easy out. The complexity of adding elements such as road conditions and other similar factors, which also affect the quality of the entire recreation experience, clearly has argued for this course of action by early researchers.

In pioneering research, Stevens (1966) attempted to alter this approach by investigating the relationship between recreation uses and water quality. In essence, his approach assumed that a change in water quality would result in a shift of the demand relationship for a particular recreational activity using a water resource. Thus, separate demand relationships would exist for different degrees of quality in a recreation experience. Recognizing that factors other than water quality are involved in the quality issue, he, nonetheless, chose to ignore those factors as a first approximation. Using quantifiable variables as proxies for water quality, he showed a positive relationship between water quality and recreation use.

Subsequent studies have built upon this effort by the addition of other variables as measures of water quality and of environmental characteristics encountered in other aspects of the recreation experience. Each has confirmed the basic hypothesis that a relationship, which is not necessarily linear, exists between factors often felt to be proxies for recreation quality and the degree of recreation activity at a particular site (Davidson, et al., 1966; Megli and Gamble; Nathan, 1969).

Yet no clear concensus emerges as to the exact relationships involved in all cases. For example, one study indicates that threshold levels of water quality exist below which no recreation use of a given type will take place and that these threshold levels may vary for different activities (Nathan, 1969). Another study was unable to confirm such a hypothesis (Megli and Gamble). As a result of such issues, the technical literation on recreation quality has not developed to the point where it is useful in a public planning context. It has, however, provided insights into the relationships involved.

THE ECONOMIC VALUE OF OUTDOOR RECREATION

Prediction of recreation attendance, although useful, does not give an indication of the economic

value derived from a particular resource or permit comparison with alternative uses of that resource. To fully evaluate the recreational use of resources, governmental decision makers need value information. To realize recreational benefits, an economic cost must be incurred for facilities and other investments. For example, water quality improvements normally require extensive capital investment programs by the public and/or private sector. To ascertain which resource use provides the greatest benefits and, thus, to determine which type of public policy is most desirable from an economic efficiency perspective, the economic value of alternative uses is required.

Measurement of the primary economic value stemming from outdoor recreational facilities or services follows naturally from the attendance prediction models discussed above. Both site oriented and market oriented demand relationships can be used for imputing monetary values to recreational activities undertaken as a result of a specific public policy action. In other words, methods have been devised for estimating the willingness of consumers to pay for participation if it were actually sold in a market place. For example, if public policy actions result in changes in water quality which in turn increase recreational uses of a particular site, estimates of the value of that change to consumers could be derived from an appropriate demand relationship and compared to the costs necessarily incurred to bring about the change. The potential value of such estimates goes without saying.

AVAILABILITY OF DATA INDICATING THE DEMAND FOR OUTDOOR RECREATION IN NATIONAL ESTUARINE ZONES

Little has changed since publication of the 1970 "National Estuary Study" which reproduced a quotation from an even earlier 1966 study by Spangler:

> The present statistics on national expenditures on ocean recreation are in such a sad state that estimates for these activities in the United States range from $50 million in 1964 according to one source to an estimated $3.86 billion in 1964 for another.
> . . . part of this 72-fold discrepency is due to the fact that statistics on expenditures for fishing, swimming, boating and related equipment do not distinguish between marine oriented activities and inland oriented activities in streams and lakes (U.S. Department of the Interior, 1970, pp. 25–26).

The "National Estuary Study" goes on to point out that secondary expenditures on outdoor recreation in estuarine zones are even more difficult to assess. Unfortunately, this state of affairs represents much of our data base regarding estuarine areas. As a result, in order to derive quantitative estimates of the amount and likely changes in outdoor recreation demand in estuarine zones, this paper is forced to depend on data which were not collected for this specific purpose. Available data will allow us to observe changes in such patterns in only a most generalized and cursory manner.

PATTERNS OF DEMAND FOR OUTDOOR RECREATION IN NATIONAL ESTUARINE ZONES, 1972–1978

As indicated above, for nationally oriented policy analysis demand functions relevant to population or market areas would be most germane. Given the availability of such estimates, a spatial allocation procedure which considers all potential recreation areas where the specific activity can take place must be used to isolate the impact on a given area (such as estuarine zones). The allocation procedures permit forecasts of recreational travel patterns, given knowledge of site capacities, travel costs, and the factors affecting consumer demand (Tadros and Kalter, 1971).

Recent analyses provide information on the demand functions for specific outdoor recreation activities in a market context. Used in conjunction with actual and forecast values of the independent variables which are assumed to cause changes in recreation demand, these functions can be used to forecast recreation use under the assumption that an adequate supply of facilities will exist. Future growth rates under alternative assumptions concerning price and other independent variables can, thus, be obtained. These rates will pertain to the actions of population groups and not to specific facilities where recreation services may be provided.

When used in conjunction with data on facility capacity and travel patterns, public decision makers have information that can be used to formulate policies which would avoid serious misallocation of limited investment capital. The result could be actions to provide additional facilities of a specific type in a given geographic area or ones which would restrict the demand focused on such areas. Cost-benefit evaluations of specific proposals would be facilititated by the data provided. Unfortunately, the necessary data and models pertaining to travel patterns and facility utilization have not been derived for activities pertinent to our nation's estuaries.

Consequently, we are forced to a second best solution. Namely, we must use information on rele-

vant demand functions to gain insight into future growth patterns and facility needs of estuarine areas. In a study by Adams, et al. (1973), demand equations were estimated, using recent (1972) data, for 17 outdoor recreation activities. For each activity, demand relationships for three types of recreation occasions (vacations, trips, and outings) were derived. These equations were then used to estimate demand during the summer of 1972 for each of the 17 activities by the populations in 171 separate geographic areas, called BEA economic areas, which together encompass the entire area of the contiguous 48 states. The BEA economic areas are delineated by the Regional Economics Division, Bureau of Economic Analysis, United States Department of Commerce. Forecasts were then made of the demand generated by the population of each area for each activity in the summer of 1978. These forecasts were based upon projections of the 1978 value for independent variables, like population, income, age, et cetera, and the estimated demand coefficients for the activities.

Of the activities analyzed, those which are particularly relevant to a study of recreation demand in estuarine zones are "fishing," "water skiing," "other boating" (boating other than water skiing, sailing, or canoeing), "other swimming outdoors" (all outdoor swimming not taking place in swimming pools), and "nature walks." Sailing or canoeing were not studied because the estimated demand equations were not statistically significant. Unfortunately, although the Adams, et al. study does permit estimation of the demand generated by specific population groups, it does not estimate where these people would go to satisfy their demand (given available facilities and costs consistent with those used for the demand forecast). Thus, we cannot say how much of the demand is currently focused on estuary resources and how much utilizes alternative sites. Moreover, the optimal type and distribution of future supply locations is well beyond the scope of available data.

Despite these shortcomings, useful information can be gained by analyzing the present and future demand for outdoor recreation activities normally associated with estuarine resources. Specifically, if we assume that the existing pattern, and changes in the future pattern, of demand generated by the population groups immediately adjacent to the nation's estuaries will reflect demand for estuarine resources, it is possible to arrive at a general picture of:

1) which type of recreation services capable of being provided by estuarine resources are currently in greatest demand;

2) which specific estuarine zones currently receive the greatest demand;

3) which type of recreation services capable of being provided by estuarine resources are likely to receive the greatest growth in demand in the near future; and

4) which specific estuarine zones are likely to be the focus of the greatest increases in demand in the near future.

The remainder of the analysis presented below reflects these assumptions.

Table 2 provides a list of the 36 BEA areas which are adjacent to the estuarine zones of the contiguous United States. The area surrounding the Great Lakes was not considered to be an estuarine zone. Figure 2 is a map showing the location of each BEA area listed in Table 2. All BEA areas in Table 2 are grouped into their respective census divisions.

Table 2 shows, for each BEA area adjacent to an estuarine zone, the population in 1972, the quantity of each activity (days) demanded by the BEA area

Table 2.—Summer of 1972 and percentage increase by the summer of 1978 in the quantity of selected outdoor recreation activities demanded by populations in BEA areas adjacent to national estuarine zones

BEA area	1972 Population		Fishing	
	(Thousands)[1]	Percentage increase[2]	Activity days (Thousands)[3]	Percentage increase[2]
New England				
1 Bangor, Maine	295.5	5	301.4	7
2 Portland, Maine	599.7	10	692.1	13
4 Boston, Mass.	5,182.3	10	5,954.0	12
5 Hartford, Conn.	2,435.9	11	2,804.1	14
	8,473.4		9,751.6	
Middle Atlantic				
14 New York, N.Y.	15,010.6	9	12,688.1	12
15 Philadelphia, Pa.	5,935.9	8	6,301.2	11
	20,946.5		18,989.3	
South Atlantic				
17 Baltimore, Md.	2,169.4	9	4,904.4	11
18 Washington, D.C.	2,501.1	12	5,814.1	14
21 Richmond, Va.	822.8	10	1,852.8	12
22 Norfolk, Va.	974.1	4	2,256.5	6
23 Raleigh, N.C.	1,282.6	4	2,620.0	5
24 Wilmington, N.C.	380.4	3	883.2	4
30 Florence, S.C.	306.4	4	642.4	5
31 Charleston, S.C.	331.1	5	758.0	7
33 Savannah, Ga.	327.9	5	718.6	6
34 Jacksonville, Fla.	649.8	9	948.3	10
35 Orlando, Fla.	784.6	14	1,822.8	15
36 Miami, Fla.	2,098.5	13	4,700.0	15
37 Tampa, Fla.	1,533.3	10	3,392.7	12
38 Tallahassee, Fla.	282.0	11	629.2	13
39 Pensacola, Fla.	300.0	5	729.9	6
	14,964.0		32,872.9	
East South Central				
137 Mobile, Ala.	561.1	8	1,265.7	9
	561.1		1,265.7	

West South Central[1]				
138 New Orleans, La.	1,675.5	8	3,692.0	10
139 Lake Charles, La.	567.5	3	1,315.2	4
140 Beaumont, Tex.	318.1	10	733.1	11
141 Houston, Tex.	1,895.5	13	4,499.5	14
142 San Antonio, Tex.	958.3	5	2,341.3	7
143 Corpus Christi, Tex.	390.3	3	980.2	4
144 Mc Allen, Tex.	258.2	1	638.7	2
	6,063.4		14,200.0	
Pacific[1]				
155 Seattle, Wash.	1,939.4	10	3,680.3	12
157 Portland, Ore.	1,351.6	10	2,517.8	12
158 Eugene, Ore.	437.0	5	829.9	7
164 San Diego, Cal.	1,128.7	10	2,196.4	12
165 Los Angeles, Cal.	8,654.5	13	15,690.8	15
170 Eureka, Cal.	99.3	7	186.7	8
171 San Francisco, Cal.	4,268.5	13	2,814.0	15
	17,870.0		32,915.9	
Total	68,878.4		109,995.4	

BEA area	Water Skiing		Other Boating	
	Activity days (Thousands)[2]	Percentage increase[3]	Activity days (Thousands)[2]	Percentage increase[3]
New England[1]				
1 Bangor, Maine	51.0	10	153.3	12
2 Portland, Maine	125.7	17	370.9	18
4 Boston, Mass.	1,381.8	20	3,433.1	20
5 Hartford, Conn.	644.6	21	1,993.9	22
	2,203.1		5,951.2	
Middle Atlantic[1]				
14 New York, N.Y.	2,938.6	27	7,298.2	24
15 Philadelphia, Pa.	1,250.8	23	3,390.2	21
	4,189.4		10,688.4	
South Atlantic[1]				
17 Baltimore, Md.	985.0	16	1,835.3	18
18 Washington, D.C.	1,366.0	20	2,483.8	23
21 Richmond, Va.	341.9	17	652.4	20
22 Norfolk, Va.	418.5	10	788.8	13
23 Raleigh, N.C.	476.6	9	925.5	13
24 Wilmington, N.C.	151.5	7	290.6	10
30 Florence, S.C.	98.8	9	194.9	13
31 Charleston, S.C.	134.5	10	254.2	13
33 Savannah, Ga.	120.5	10	234.9	13
34 Jacksonville, Fla.	368.7	14	703.3	17
35 Orlando, Fla.	364.9	19	711.6	22
36 Miami, Fla.	934.5	21	1,822.5	24
37 Tampa, Fla.	610.5	16	1,282.5	19
38 Tallahassee, Fla.	111.4	17	216.7	20
39 Pensacola, Fla.	141.3	9	267.3	12
	6,622.3		12,664.3	
East South Central[1]				
137 Mobile, Ala.	223.6	13	432.4	16
	223.6		432.4	
West South Central[1]				
138 New Orleans, La.	671.0	15	1,278.9	19
139 Lake Charles, La.	224.3	8	420.1	12
140 Beaumont, Tex.	137.7	16	263.7	19
141 Houston, Tex.	931.1	19	1,727.3	22
142 San Antonio, Tex.	462.0	11	853.3	15
143 Corpus Christi, Tex.	194.0	7	352.5	11
144 Mc Allen, Tex.	118.4	5	210.4	10
	2,738.5		5,106.2	
Pacific[1]				
155 Seattle, Wash.	985.7	10	1,616.7	19
157 Portland, Ore.	636.1	8	1,101.3	16
158 Eugene, Ore.	198.5	3	349.1	11
164 San Diego, Cal.	574.3	10	935.6	19
165 Los Angeles, Cal.	4,249.3	15	7,019.6	23
170 Eureka, Cal.	44.6	5	77.6	14
171 San Francisco, Cal.	2,137.5	15	3,502.7	23
	8,823.0		14,602.6	
Total	24,802.9		49,045.1	

BEA area	Other swimming		Nature walks	
	Activity days (Thousands)[2]	Percentage increase[3]	Activity days (Thousands)[2]	Percentage increase[3]
New England[1]				
1 Bangor, Maine	987.1	7	169.6	10
2 Portland, Maine	2,351.2	12	414.5	15
4 Boston, Mass.	21,656.4	13	4,029.1	17
5 Hartford, Conn.	10,057.8	15	1,848.1	18
	35,052.5		6,461.3	
Middle Atlantic[1]				
14 New York, N.Y.	48,313.4	15	9,125.4	19
15 Philadelphia, Pa.	23,068.0	13	4,248.9	16
	71,421.4		13,374.3	
South Atlantic[1]				
17 Baltimore, Md.	8,234.4	13	1,460.2	16
18 Washington, D.C.	8,438.2	18	1,988.4	20
21 Richmond, Va.	1,282.6	15	489.6	17
22 Norfolk, Va.	2,803.8	8	658.9	10
23 Raleigh, N.C.	3,230.8	8	719.2	9
24 Wilmington, N.C.	1,011.3	6	221.7	7
30 Florence, S.C.	679.6	8	147.4	9
32 Charleston, S.C.	911.0	8	207.4	10
33 Savannah, Ga.	822.4	8	188.3	10
34 Jacksonville, Fla.	2,424.1	12	562.9	14
35 Orlando, Fla.	2,328.2	17	544.7	19
36 Miami, Fla.	5,957.0	19	1,458.4	21
37 Tampa, Fla.	3,957.5	14	949.2	16
38 Tallahassee, Fla.	744.3	15	167.9	17
39 Pensacola, Fla.	926.5	8	212.0	10
	42,661.1		9,976.2	
East South Central[1]				
137 Mobile, Ala.	1,504.9	11	347.2	13
	1,504.9		347.2	
West South Central[1]				
138 New Orleans, La.	4,489.3	13	1,047.2	15
139 Lake Charles, La.	1,500.6	7	343.2	8
140 Beaumont, Tex.	899.7	14	212.0	16
141 Houston, Tex.	5,961.9	17	1,410.7	19
142 San Antonio, Tex.	2,987.2	9	705.2	11
143 Corpus Christi, Tex.	1,253.1	6	295.2	8
144 McAllen, Tex.	774.7	4	171.3	5
	17,866.5		4,194.8	
Pacific[1]				
155 Seattle, Wash.	6,953.7	13	3,026.0	15
157 Portland, Ore.	4,647.5	12	2,045.8	14
158 Eugene, Ore.	1,469.9	7	644.5	9
164 San Diego, Cal.	4,163.0	13	1,806.9	15
165 Los Angeles, Cal.	30,796.6	17	13,653.9	18
170 Eureka, Cal.	326.6	9	142.6	10
171 San Francisco, Cal.	15,268.4	17	6,735.0	19
	63,625.7		28,054.7	
TOTAL	232,232.1		62,408.8	

[1] Census Division Name.
[2] Adams et al., p. 160.
[3] Ibid., p. 84.
[4] Based on unpublished data from the 1972 National Recreation Survey.

FIGURE 2.—BEA regions encompassing U.S. coastal zone.

population during the summer of 1972 on all recreation occasions, and the percentage increase in demand forecast for the 1972–1978 time period for the activities mentioned. Only activities relevant to the estuarine zone are considered. In each case, the U.S. average cost for each activity and each occasion, as calculated from the 1972 National Recreation Survey, was used in the analysis. No change in this price over time was assumed. Thus, by implication, patterns and government pricing policy were considered constant.

What is not known or shown in Table 2 is the spatial allocation of the 1972 recreation use or forecast changes in such use patterns. Since the BEA regions differ in geographic size, individuals residing in a region are located at various distances from its boundaries, and round trip distances for travel on various types of recreation occasions differ, the distribution of recreation demand stemming from a given region cannot be proportioned between it and other regions without indepth analysis. However, the 1972 National Recreation Survey data does provide some information pertinent to the issue of recreation consumption in a given BEA region which contains an estuarine zone. Table 3 indicates the distribution of recreation activity, for our selected activities, in 1972 between different types of occasions.

Table 4 shows the distribution of round trip miles for the same activities and occasions. Note that a minimum of 60 percent of all participation in the selective activities takes place on trips and outings and that at least 60 percent of this amount occurs within 400 miles of home. The figures are substantially higher for some activities. Even for vacations, 15 to 20 percent of the activity occurs within a one day round trip of the participant's

Table 3.—Percent of summer participation in selected outdoor recreation activities on vacations, trips and outings (1972)

Activity	Percent on vacations	Percent on trips	Percent on outings
Fishing	29.3	19.6	51.1
Water skiing	19.4	16.6	64.0
Other boating	35.0	29.3	35.7
Other swimming outdoors	30.9	15.8	53.3
Nature walks	40.2	22.3	37.5
Average for all activities	31.8	13.9	54.2

Source: 1972 National Recreation Survey

Table 4.—The distribution of round trip miles traveled on vacations, trips and outings by activity* (June-August, 1972)

Round trip mileage	All activities			Fishing		
	Percent vacations	Percent trips	Percent day outing	Percent vacations	Percent trips	Percent day outing
0–800	17.8	60.0	100	21.8	66.9	100
801–4000	51.9	33.4		57.2	33.0	
4001–8000+	30.8	6.7		25.4	0.0	
Round trip mileage	**Water skiing**			**Other boating**		
	Percent vacations	Percent trips	Percent day outing	Percent vacations	Percent trips	Percent day outing
0–800	21.5	85.4	100	16.6	73.6	100
801–4000	37.5	14.6		47.2	26.4	
4001–8000+	40.8	0.0		36.0	0.0	
Round trip mileage	**Other swimming**			**Nature walks**		
	Percent vacations	Percent trips	Percent day outing	Percent vacations	Percent trips	Percent day outing
0–800	19.6	68.0	100	14.0	61.4	100
801–4000	45.6	19.4		46.5	28.5	
4001–8000+	34.9	12.7		39.7	10.0	

*Outing trips for all activities never exceed 150 round trip miles regardless of activity.
Source: 1972 National Recreation Survey.

home. The implication is clear. Although cross-boundary movements of recreation participants may not net to zero for a given region, demand for regional facilities tends to be concentrated in the nearby population. After taking account of cross-boundary recreation movements, the total demand for regional facilities is unlikely to vary much from the total demand forecast for the regional population.

Based on the total number of activity days demanded in all 36 BEA areas for each activity, the activity in greatest demand is "other swimming outdoors" followed in order by "fishing," "nature walks," "other boating," and "water skiing." When looking at the ranking of activities for each census division, "nature walks" and "other boating" switch positions in the ranking for the South Atlantic, East South Central, and West South Central census divisions.

Looking at the individual BEA areas adjacent to estuarine zones, Table 2 indicates the greatest amount of demand is generated by the population of the New York BEA area for "other swimming outdoors" followed in order by the same activity in the Los Angeles and Boston BEA areas. The fourth greatest number of activity days demanded is for "fishing" in the Los Angeles BEA area followed by "other swimming outdoors" in the San Francisco area and "fishing" in the New York area. In all areas, the demand for estuarine resources and facilities appears to be greatest for those resources associated with swimming and fishing.

While it is important to know what type and where estuarine resources are currently in greatest demand, this information, by itself, is not enough for formulating public policy. It is of greater importance to have information on which demands for which types of estuarine resources will be growing most rapidly in each estuarine zone in the future. The estimated percentage increases in quantity demanded shown in Table 2 indicate that the outdoor recreation activities currently in greatest demand are not necessarily those projected for the greatest future growth rate. For the United States as a whole and for the five activities under consideration in this study, "other boating" is expected to grow the fastest between 1972 and 1978 with a percentage increase of 18 percent. Following "other boating" are "water skiing" and "nature walks," each expected to grow by 15 percent, "other swimming outdoors" at 13 percent, and "fishing" at 11 percent.

A similar ranking of the percentage increases in demand for the five activities is reflected in Table 2 for the individual BEA areas. The principal difference is that "water skiing" and "nature walks" change places in the number two ranking, depending upon the census division under consideration.

Table 2 also shows that many of the BEA areas which show the greatest levels of demand are also the areas which show some of the highest projected percentage increases between 1972 and 1978. For example, the projected 27 percent increase in demand for "water skiing" in the New York BEA area is the highest for all areas listed in Table 2. The New York BEA area also has the second highest level of demand for "water skiing," surpassed only by the Los Angeles area. Likewise, the second highest of all growth rates shown in Table 2 is 24 percent for "other boating" in the New York and Miami areas. The level of "other boating" demand generated by the New York BEA area is the highest level (7,298,200 activity days) of all areas listed in Table 2. Even when a rapid rate of growth in demand is associated with lower initial levels, the growth rate may be enough, by itself, to create significant strains on the ability of the estuarine resources to absorb the increases. It appears, from Table 2, that the greatest strain on any single type of outdoor recreation resources in estuarine zones will be on "other boating" facilities in the New York, Miami, Washington, D.C., Los Angeles, and San Francisco areas. The "other boating" demands in all of these BEA areas are projected to grow by 23 percent or more.

RECOMMENDATIONS

Through Table 2, we have provided a rough indication of the facilities and resources in specific estuarine zones currently subjected to the heaviest demand, as well as those likely to face the greatest future increases in demand. Current capacity and, consequently, future facility needs cannot be identified from available data. More importantly, it is obvious that recreation sites other than those located in estuarine zones could serve as supply sources for this demand. The role of these alternative sites, for current and future policy actions, is critical to planning for the estuarine zones. Thus, only general recommendations for policy action can be given.

The principal issue involved relates to financing any additional facilities and resources and the policy implications of the financing methods. Many outdoor recreation facilities and resources are provided by the public sector at little or no charge to the facility users. In many cases this is a valid policy such as when there is no administratively feasible way to collect entrance fees or when a level of government makes a conscious decision to redistribute income by providing outdoor recreation facilities free of charge. In the former case, the failure to collect fees is justified because it would cost more to collect the fees than could be offset by the revenues from the fees. In the latter example, free provision of outdoor recreation facilities may be valid on the basis of equity, if these portions of the population who warrant free access actually make use of the facilities. When reasons such as these are not involved in the decision to provide free facilities, however, a serious distortion in the allocation of resources arises.

> Public investments, however, are often made with little attention to market prices. This is particularly true of sport fishing and boating where the public often provides hatcheries, public piers and marinas at artificially low costs to the user. This situation, in effect, may create an 'artificial demand,' with the attendant environmental pressures, and heavy use of estuarine and other resources . . . public policy must weigh not only abstract 'demands' derived from proxy data, but attempt to more fully assess net benefits and costs of public recreational investments (U.S. Department of the Interior, 1970, p. 28).

One way to more fully assess net benefits and costs of public recreational investments is to charge realistic entrance or user fees for the facilities provided. The price paid by the recreationalist is a measure of his willingness to pay and the value of the recreation experience to him. When the users of a recreation facility are willing to pay a price which is great enough to cover the full cost of providing the facility, we have an indication that the benefits to society are at least equal to the costs to society of providing the facility. Assuming there is no equity (income redistribution) goal involved, if people are unwilling to pay a price which is sufficient to cover the full costs of the facility, the facility should not be provided since the costs to society will exceed the benefits.

Adams et al., (1973), provide evidence that increases in the prices of the five activities considered in this study will have a relatively small impact upon the quantity of each activity demanded by people who participate. The evidence takes the form of price elasticities of demand which are defined as the percentage change in the quantity of an activity demanded that is caused by a one percent change in the price paid for that activity. Table 5 provides the estimated price elasticities of demand for each of the five activities consumed on each of the three types of outdoor recreation occasions. For example, the price elasticity of demand for fishing on vacations is estimated to be −.24. This means that a one percent increase in the price of fishing will cause only a .24 percent decrease in the quantity of fishing demanded on vacations.

A system of full cost pricing of estuarine resources used for satisfying outdoor recreation demand for fishing, other boating, other swimming outdoors, water skiing, and nature walks can and should be employed in those estuarine zones where such a policy does not now exist. Such a policy will assure that the benefits derived will at least equal the costs of providing additional estuarine resources. Table 5 indicates this policy of rational allocation of resources can be employed with relatively little impact upon the quantities of the recreation activities demanded. This policy will be especially crucial to the survival of those estuarine zones identified above which are facing the heaviest demands and the most rapid growth of future demands.

Critics of this recommendation point out that project or investment economics are only one aspect of the possible implications which may be important politically and socially. Equity effects, for example, were referred to briefly earlier in this section. Re-

Table 5.—Estimated price elasticities of demand for selected outdoor recreation activities on vacations, trips, and outings

Recreation activity	Vacations	Trips	Outings
Fishing	−.24	−.27	*
Water skiing	−.20	−.17	−.32
Other boating	−.23	−.18	*
Other outdoor swimming	−.24	−.20	−.19
Nature walks	−.22	−.18	−.07

*Not statistically significant.
Source: Adams et al., 1970, p. 79.

gional impacts are one form of equity effect that has traditionally been important to recreation development considerations. Trade-offs may be implicit between such impacts and the pricing recommendations suggested previously. Higher entrance fees will have some effect on participation and, consequently, on regional expenditures. For example, recreation is often of interest to a region because of its export characteristics (non-residents spend money for use of the region's resources). Such expenditures may create employment opportunities for the regionally unemployed and normally result in a multiplier effect on the sales and income of other economic sectors in the region.

Direct regional income impacts can stem from two sources. First, the regional impact in terms of facility construction and maintenance must be considered. When such facilities are wholly or partially financed by non-regional funds and some of these funds are spent on inputs supplied by the region, the economy of the area is benefitted (Nathan, 1966). On the other hand, if all construction funds were raised regionally or had to be paid back by regional interests, only an internal transfer effect would occur. Second, increased expenditures in the region by recreationists who are non-residents or increased expenditures by residents through the interregional reallocation of recreation consumption patterns can beneficially affect a regional economy. Of course, both of these factors must also be offset by reimbursement considerations, taxes due directly to construction, and increased taxes required to finance additional public services in the region resulting from use of the recreation area (i.e., increased police and fire protection, et cetera).

Knowledge of direct expenditures in a region enables estimates of the multiplier or indirect impacts to be made. The more economically self-contained the area, the greater will be the multiplier value since less of the initial and subsequent round expenditures will flow to other regions. Since increased regional expenditures for recreation related goods and services can be substantial, their impact can be considered a real benefit to the region where a recreation facility is located. From the national point of view, however, both direct expenditures and their subsequent multiplier implications are normally classified as transfer effects. That is, to the extent the region is successful in attracting this type of expenditure, it will be detrimental to other areas. Moreover, regional gains must be offset by the problems created by the increased recreation activity. For example, employment in many economic sectors servicing recreation is highly seasonal, low paid and often recruited from outside the area. Requirements for government services may also increase (including off-season unemployment benefits), causing increased taxes. On balance, the regional implications of increasing recreation demand and the provision of facilities to satisfy that demand is an empirical question which must be answered for each specific region. Although net gains to one region can normally be considered as losses to other regions such distribution effects may be a conscious political decision affecting facility location. From a national perspective, however, a uniform system of public pricing with respect to federally funded facilities would not, in principle, give undue advantage to one region over another in terms of such regional impacts. In other words, a nationally imposed pricing system for use of estuarine areas would be expected to affect all regions in a uniform way. Only if a differential pricing schedule between regions was installed could a contrary result occur. Although differential pricing should not be rejected as a means for excluding peak demands for facilities, both in time and space, it is not currently a viable approach to the nation's recreational problems.

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THE VALUE OF ESTUARINE FISHERIES HABITATS: SOME BASIC CONSIDERATIONS IN THEIR PRESERVATION

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ABSTRACT

Comprehensive management of estuarine environments is confronted by the valuation issue—attaching relevant societal values to the degradation or improvement that accrues to fisheries and their habitats from manmade changes.

The estimation of the social and economic costs and benefits due to change in an estuary should follow a careful appraisal of the ecological effects. The backwardness of the art of assessing damage is evident in the meager and piecemeal state of knowledge of what damages have occurred and are presently accruing. Tenets of economic good sense, however, offer useful guidance. The relative scarcity of the aquatic habitat and of critical natural features in the estuary support system cannot be overlooked. Availability of substitutes and substitute sites is a basic consideration. The full arsenal of economic reasoning has to be employed to provide insight to alternative courses of estuarine management.

Two broad sources of degradation of fishery habitats are foreseen as resulting from population growth and economic development. Direct pollution of nutrients and toxic materials is the first source.

The physical alterations are the second source. Three intensifications of use are identified as compounding the difficulty of maintaining fishery resources in estuaries: (1) increasing loads of municipal and industrial wastes; (2) the leakage of petroleum and petroleum products into estuaries; and (3) upstream activities affecting freshwater inflows.

Land and water use in the coastal zone is interrelated with that in the hinterland. There is an urgent need to improve environmental impact statements so that the full extent of the values is displayed for the decision makers. A major national commitment in training, research, and funding is involved in staffing state and federal agencies with the economic and biological expertise necessary for the informed management of the nation's estuaries.

INTRODUCTION, OVERVIEW AND PERSPECTIVE

The demands of society for fish and wildlife, the demands for segments of their estuarine habitat for other uses, and, last but not least, the total array of spillover effects of agricultural and industrial production on fish and wildlife and their habitats are compounding the problem of conserving their estuarine and coastal zone support system.

This was one of the principal findings of the "National Estuarine Pollution Study" and the "National Estuary Study" in appraising the status and conditions of estuarine fisheries habitats in 1970.[1] In the interim, there is little substantive and quantitative evidence to confirm that the demands for many of the different services of the estuarine zone have diminished or that their adverse impacts have lessened. While some offsetting tendencies have evolved and promise respite from the continuing erosion of estuarine habitat, the negative impact of these forces of change is still substantial and increasing as the competition for the uses of estuarine resources responds to population growth and economic development.

In contrast to the 1960's a more populous and wealthy society is now more environmentally alert and presumably better informed as to the overall values of estuaries; legislation has been enacted to permit their use for fish production among other purposes.

Nevertheless, a fundamental difficulty still confronts comprehensive management of estuarine environments—relevant values have to be attached

[1] "The National Estuarine Pollution Study" was authorized by Section 5(g) of the Clean Water Restoration Act of 1966, P.L. 89-753, approved November 3, 1966. The study was published March 25, 1970, as Senate Document No. 91-58, 91st Congress, 2nd Session. The Estuary Protection Act, P.L. 90-454, authorized the Secretary of the Interior to study estuary conditions and report to Congress. The result was the National Estuary Study, U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., January 1970.

to the degradation or improvement which accrues to fisheries habitats from changes in the estuarine environment.

Logically, estimation of social and economic costs and benefits from ecological change in an estuary should follow a careful appraisal of the ecological effects. Is the planned change in the estuarine environment with its associated impact on the shell and fin fisheries worth it? Can benefits be increased and detrimental effects reduced by modifying this change? These questions obviously are best answered when the positive and negative impacts are identified and measured prior to assessing whether it is in society's interest to undertake the change, however small it may appear to be.

The purpose of this paper is to deal with some aspects of the complex and perplexing evaluation issue as it relates to estuarine fishery habitat. Degradation, definable in quantitative terms pertaining to fishery productivity, is also elusive. Only crude indicators are available. There are significant forces such as projected future depletion of freshwater flows in estuaries, buildup in pollutants from diffuse sources and pressures for the alteration of estuarine lands. There is, consequently, an urgent necessity to review the performance of the ameliorative measures taken to date, to make the required adjustments and, where needed, to institute new management systems and practices. This paper attempts to give an overview of the estuarine management problem as it relates to the accountability of fishery values in the short and long term, and how they might be afforded better protection by incorporating sound principles into the evaluation procedure. It does not presume to identify and assess the present status of the estuarine habitat for fish production other than in broad terms. A comprehensive treatment of the latter will demand appraisal by competent authorities in many specializations—a herculean task outside the terms of reference of the present paper.

DEGRADATION OF FISHERIES HABITATS: AN ELUSIVE AND COMPLEX PHENOMENON

The two earlier studies mentioned in the introduction complemented each other, emphasizing the paucity of reliable benchmarks for assessing the exact nature and extent of the damage to estuarine fisheries habitats. These studies pointed to the inadequacy of knowledge (including techniques and instrumentation) to diagnose principal causes affecting the health and productivity of this habitat. Prescription of remedial measures then, in 1970, could be contemplated only with great reservations and little certainty that they were least costly or most effective. There is little concrete evidence that the faculty and facility for prognosis, diagnosis and remedy have improved in the interim.

"The National Estuarine Pollution Study" found that "for the majority of the Nation's estuarine systems, there are little or no data to describe existing water quality conditions . . .." [2] and that while the effects of physical destruction of the habitat are also easy to assess at least in terms of immediate damage caused, the more subtle related effects of organisms dependent indirectly on the habitat for food supply are more difficult, sometimes impossible, to determine. In summary, "it is not possible to say whether 38 percent of the Nation's estuarine systems are undamaged or merely present no identifiable problems at this time." [3]

The last intensive effort to inventory national estuarine conditions in the late 1960's resorted to gross indicators to typify degradation—water quality of major rivers and streams entering the estuarine area, the area of wetlands lost, the area of finfish habitat affected by water pollution, the areas of shellfish lost or closed, and the number and type of modifying structures.

It might be concluded after reveiwing more recent literature that assessment of the degradation of the total system for different estuaries and its likely effects on fishery productivity would prove to be equally difficult, for the same reasons. The interactions of basic processes are still imprecisely understood; the complexity of interactions and reactions defies the easy transfer of lessons learned in the laboratory or under actual field conditions to protect or improve fishery habitats. Usually they deal with only a few of the critical variables and a few states of nature of the total system. Advances in knowledge and the state-of-the-art in the last five years would have had to be substantial and significant to effect any improvement in the diagnosis and prognosis of the health of the estuarine habitat.

In the late 1960's, the rate of change brought about by economic activity in the estuarine zone could not be identified and work by ecologists at that time was appraised as "generally concerned with identification of system types, the development of general theory, and the measurement of system characteristics and operating phenomena. Much is known about certain elements of estuarine ecological systems, such as temperatures, salinities, abundance

[2] "The National Estuarine Pollution Study," p. 269.
[3] Ibid., p. 272.

of certain biotic communities, but the specific processes and causal relationships of complex whole systems and interacting subsystems have only recently been partially understood." [4]

A quantitative assessment of the trend in estuarine ecological system modification-degradation was not feasible; all that could be observed were three general effects and a qualitative trend.

To the three principal forms of modification brought about in estuaries as a result of man's activities—significant waste discharges, dredging and filling, and constructing physical structures on fresh water inflows or in the estuaries themselves—were attributed three generalized effects:

1. Productivity of biotic communities is generally reduced due to many factors, including reduction or over-provision of nutrients, abrupt changes in temperatures and salinities, changes in circulation patterns, and destruction of physical components of the system.
2. Specie diversity and organization are simplified.
3. Trends toward severely modified ecosystems are established.[5]

The assessment was made "that most, if not all, major estuarine areas in the continental United States are now or soon will be affected by disturbances of more than one identifiable type. These systems are characterized by heterogeneous patches of chemicals, fertilized waters, waters low in available oxygen, turbidities, acids and other conditions alien to normal life of estuarine ecosystems. The multiple stressed situation is possibly the nation's most urgent estuarine problem because the condition is a mixture and the causes several. The stress of many different kinds of wastes may be more difficult for an ecosystem to adapt to than separate types of wastes acting alone." [6]

Important estuaries such as Boston Harbor, New York Harbor, Raritan Bay, portions of Chesapeake Bay, Tampa Bay, Galveston Bay and San Francisco Bay were subject to major sources of modification which resulted in identifiable stress in more than one of the estuaries' subsystems. Twelve major sources of modification were attributed to the development of the petrochemical complex in Galveston Bay. These caused stress in seven identifiable systems. Multiple-stressed systems characterized many estuaries, and man's activities tended to increase the number of stressed systems and the degree of stress.[7]

A crude network analysis of some of the impacts and the changes brought about in an estuary as a result of a single modification—dredging—is shown in Figure 1. It illustrates the complexity of the interactions which investigators have to identify and specify in tracing the effects on an aquatic ecosystem subject to many modifications of varying intensities diurnally and seasonally.

That considerable research is needed to adequately predict the effect of erosion, siltation, and sedimentation on an aquatic ecosystem in a farm pond highlights the difficulty and the magnitude of the research effort which would allow us to predict the effects of many and simultaneous changes in an estuary.

In summary, the complexity of the estuarine systems themselves and of the responses to man's activities precluded any realistic attempt to assess national and regional trends in the estuarine environment. "At this stage of knowledge such trending based on scientifically tested information is impossible." [8]

The present status of estuarine health for fish production eludes detailed specific diagnosis; however, certain obvious symptoms can be detected. An attempt is made in Table 1 to classify selected estuaries by the degree of modification, water quality, and reported effects on fish life as evidenced in finfish kills and shellfish areas closed.

Only a partial, sometimes misleading, picture of the habitat's status is obtainable from these gross indicators. Fishery productivity measured in terms of the catch of edible species presumably is a useful indicator of the estuarine habitat. But again there is a difficulty in disentangling the effects of overfishing and other natural causes from those stemming from manmade changes in the area.

The decline of fishery productivity is not a new or recent phenomenon. An underlying condition for a century or more, in estuaries it has been especially accentuated by the social and economic changes accompanying economic growth which has been centered largely around the nation's estuaries.

And economic demands and the supply possibilities chosen by society to turn out its products and services continue to create situations in the estuarine

[4] "The National Estuarine Pollution Study," pp. 305-306. These remarks should not be construed to indicate that there is the presumption or the competency to assess the present state-of-the art.
[5] "The National Estuarine Pollution Study," p. 306.
[6] "The National Estuarine Pollution Study," p. 308.
[7] "A stress on an estuary is a process which drains available energy. Stress can be either direct as in the case of harvesting finfish or shellfish from the system, or indirect as happens when increased turbidities shade out light or when some substance such as phenol is added to the aquatic system, either causing mortality or demanding special adaptive work on the part of surviving organisms to sustain life. Energy drains on existing organisms may also occur when excesses of nutrients added to the system deplete the available oxygen necessary for respiration." Ibid., p. 305.
[8] "The National Estuarine Pollution Study," p. 308.

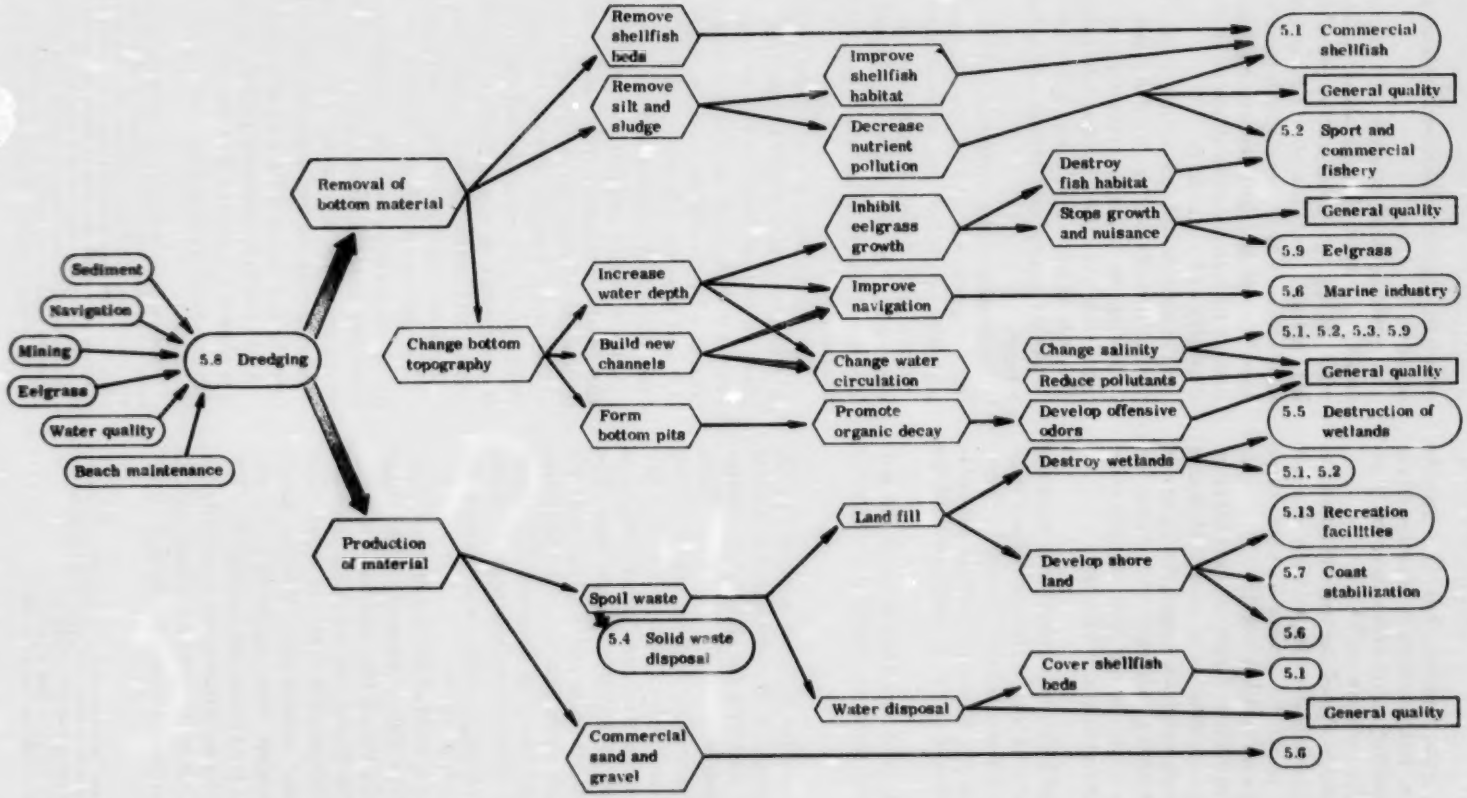

FIGURE 1.—A network analysis of dredging. Source: National Shoreline Study, Shore Management Guidelines. Department of the Army, Corps of Engineers, Washington, D.C., August 1971, p. 36. Original source: Ellis, R. H., et al, 1969. The Development of a Procedure and Knowledge Requirements for Marine Resource Problems of Nassau and Suffolk Counties. The Travellers Research Corp., Hartford, Conn.

Table 1.—Assessment of status of selected estuarine zones[1]

Biophysical region	Location	Degree of modification[2]	Water quality status	Major reported effects
North Atlantic	Penobscot Bay	Moderately Modified	Coastal industries are primarily textile, leather, and machinery. No major water quality problems.	
Middle Atlantic	Narragansett Bay	Moderately-Severely Modified	Site of major naval base and various industries. A major port facility. Municipal sewage and industrial waste are major pollution problems.	Prohibition of shellfish harvesting in specified areas.
Middle Atlantic	Delaware Bay	Severely-Moderately Modified	Extensive water quality problems exist resulting from the inadequate treatment of municipal waste water compounded by sewer overflows.	
Chesapeake Bay	Susquehanna River	Moderately-Severely Modified	Significant mine drainage in upper basin. Sediments are a nonpoint source pollutant in the lower basin.	
Chesapeake Bay	Potomac River	Severely Modified	A classic example of the effects of large quantities of municipal wastes on an estuary. During warm summer months dissolved oxygen levels approach zero.	Waste discharge effects are measurable for 20 miles along the river.
South Atlantic	Savannah River	Severely-Moderately Modified	The lower basin is sparsely populated. Only small quantities of municipal and industrial waste are received.	
South Atlantic	St. John's River	Moderately Modified	Large loads of domestic wastes are received. Algal and weed problems are frequent, in addition to high turbidity.	Fish kills have occurred on occasion.
Gulf of Mexico	Apalachicola Bay	Moderately Modified	Limited development emphasis on commercial fishing and recreation; however, municipal wastes are a problem.	Bacteriological problems have forced closure of most shellfish harvesting.
Gulf of Mexico	Mobile Bay	Severely Modified	Estuarine degradation resulting from municipal and industrial wastes, in addition to extensive physical modifications.	Highly sensitive shellfish industry threatened by increasing pollution.
Gulf of Mexico	Mississippi River	Severely Modified	Phosphorus and nitrogen sufficient for algae growth and getting worse. Phenols and hydrocarbons levels high: Municipal and industrial sewage a primary factor.	Elimination of commercial fishing below St. Louis, Missouri and Baton Rouge, Louisiana.
Gulf of Mexico	Galveston Bay	Severely Modified	Concentrated industry, along with extensive channeling, dredging, and other modifications. Water quality has been significantly lowered.	Shellfish harvesting limitations have existed in many areas for the past 20 years.
Pacific Southwest	San Diego Bay	Severely Modified	Site of large naval base, extensive land fill and other modifications. Municipal wastes being cleared up.	Loss of much of the marshlands.
Pacific Southwest	San Francisco Bay	Severely Modified	Heavy concentrations of industry and population are the source of large quantities of waste. Numerous areas deficient in dissolved oxygen.	Shellfish harvesting restricted. Numerous fish kills.
Pacific Northwest	Columbia River	Moderately Modified	Supersaturation of gases from dams along river. General water quality is good, with no overall changes in past six years.	Some fish kills from supersaturation.
Pacific Northwest	Puget Sound	Moderately Modified	Water quality affected mainly by municipal and industrial wastes, as well as by agriculture and silviculture.	

[1] Sources: Environmental Protection Agency, Office of Water Planning and Standards. August 1974. National Water Quality Inventory, 1974 Report to the Congress. EPA-44019-74-001, Washington, D. C.
United States Department of the Interior, Fish and Wildlife Service. August 1970. National Estuary Study, Volume II, Washington, D. C.
National Estuarine Pollution Study. August 1970. Report to the Secretary of the Interior to the United States Congress, 91st Congress, pursuant to Public Law 89-753, The Clean Water Restoration Act of 1966, Washington, D. C.

[2] Relatively unmodified refers to an estuary approaching its natural state. Moderately and severely modified estuaries are defined as those areas undergoing limited and extensive development, respectively. None of the selected locations qualified as relatively unmodified.

and coastal zones where fisheries (and wildlife habitats) are, with few exceptions, subject to continuing encroachment and degradation. Fish and wildlife habitat in many instances become the residue of the present process—that is, what remains after all the deductions and the deleterious external effects have exacted their full measure.

That economic activities could be conducted in a way to reduce these impacts without incurring great costs underlies recent legislation to reduce the nega-

tive effects of these other production processes on the estuaries' production of finfish and shellfish.[9]

State and local governments have enacted additional legislation aimed in general at reducing the detrimental impacts of economic growth on the estuarine resource. A summary of coastal and estuarine zone legislation is given in Appendix Table 1 for the coastal states and Hawaii. The table shows that actual plans for coastal and estuarine management, with the exception of North Carolina for which a preliminary plan was prepared in 1970, are not yet in existence although legislation affording protection to coastal wetlands and tidal marshlands has been enacted in most of the states.

However, for reasons already given it is difficult to assess the efficacy of these measures since they have been in operation only a relatively short time. It takes time to repair delicate biological systems and to build up fish stocks. Besides, rehabilitation of fish stocks is subject to fishing pressures and natural changes not directly attributable to man. Little is known about the relative significance of man-caused stresses such as overfishing and naturally occurring stresses on estuarine-dependent finfish and the productivity of their habitat.

The backwardness of our skills in assessing the damage to estuarine biota can only be judged as serious when viewed against the increasing competition for the uses of most of the nation's estuaries. Failure to devise adequate monitoring and design management to conserve the fisheries resource and its habitat while equitably allocating estuarine resources to various uses, increases the likelihood that degradation by gradual attrition will be the fate of many estuaries.

Damage assessment is fundamental to the valuation issue. The value of a segment of estuarine fishery habitat may be defined as what an informed society would exchange for it in terms of the proceeds from a non-fishery use.

It has been argued that the damage to the estuarine fisheries habitat by the direct killing of commercial and sport species, by the elimination of a necessary food supply, or by damage to the reproductive capability of any link in the food chain brought about by other competing uses is difficult to establish. Damage may be, and often is, difficult to detect. This simply emphasizes that it is essential to know what fish and wildlife and habitat values are being destroyed and when their value is sufficient to buy off further encroachment or deleterious side effects of other uses.[10]

COMPETITION FOR USE AND THE VALUATION PROBLEM

Increasing competition for the use of the estuarine habitat resources is central to their present and future management concerns. The perennial challenge to management is to allocate according to value while avoiding irreversibilities.

The crux of the problem in the estuarine zone is how to allocate its resources to obtain the highest long-term net social value. The relative importance of the various demands and the benefits to be received have to be evaluated. Any manmade alteration, development, or management should account for both market and extramarket values stemming from a productive fisheries habitat as well as for those essentially market products from other uses of the estuary—cooling water, waste disposal, transportation, land fill, et cetera.

The resources involved—land, tidelands, marshes, wetlands, free flowing streams, et cetera—have alternative uses. The preservation of estuarine land and water for fish production can incur high cost in terms of the proceeds from other uses that are forfeited. Benefits that society foregoes from not using this water and land to produce power, water supply, waste disposal, industry and home real estate, in some instances, are considerable; in other situations, very few benefits are forfeited to retain healthy estuarine fishery habitat. A policy of safe minimum standard to retain fish production may require a very small insurance premium to avert what might prove to be substantial losses to society in the long run.[11]

A comprehensive evaluation of these fish production resources is consequently urgent and fundamental. Only then will society be able to see in perspective the loss-benefit balance of the many uses of estuarine resources. At this point, the neces-

[9] The criteria and guidelines society adopts for the conduct of economic and social activities as they impinge on the estuarine environment are not unalterable as major federal legislation relating directly or indirectly to the preservation of the quantity and quality of estuarine fishery habitat that has come into force since 1969 clearly testifies. The conduct of economic activity may be broadly interpreted to include the way people live, work, recreate, and are housed and transported in the estuarine zone. The following is a list of some of the more significant federal acts:

1969—National Environment Policy Act
1970—Environmental Quality Improvement Act
1972—Coastal Zone Management Act
Federal Water Pollution Control Act Amendment
Marine Mammals Protection Act
Marine Protection, Research and Sanctuaries Act
Pesticide Control Act

[10] Environmental forecasting is still in its infancy although the National Environmental Policy Act has been in force some five years. Substantial effort is now under way in "an attempt to find methodologies for forecasting the impact of man's activities on flood plains and coastal zones." The Environmental Law Institute and the International Biological Program of the National Science Foundation have focused their research efforts on these two ecosystems. Environmental Quality, The Fifth Annual Report of the Council on Environmental Quality, December 1974, pp. 409-410.

[11] The safe minimum standard as an objective of conservation policy is discussed by S. V. Ciriacy-Wantrup in Research Conservation Economics, Revised Edition, University of California Press, 1963, pp. 251-270.

sity for effective management for maximum benefits and minimum losses will become clear.

While an appropriate calculus surely should be devised, this has proved to be no easy task. The admixture of market and extramarket values makes reliable estimation difficult if not impossible.

Many of the estuarine values apply to uses such as sport fishing, boating and aesthetic enjoyment—activities for which there are no formally organized market places where monetary worth can be measured. These are extramarket values for which at best proxies may be devised.

Values established in the market place are not available for all the services provided by a productive estuarine fishery habitat; those extramarket benefits—days of sport fishing, clam bakes, et cetera—nevertheless are real, of worth to society and might be assumed to be increasing as natural estuarine areas diminish.

Values for estuarine resources are also set by the non-market system as in the legislative process which expresses choices indicating social costs and benefits not measured in marketplace terms. The acts of state legislatures to conserve estuarine marsh and wetland habitat illustrate this process of social choice.

Many of the "services" produced by an estuary are joint products—a commercial fish catch is dependent on the estuarine habitat but the estuarine zone also provides safe anchorage for the fishing fleet.

Where substantial benefits, in terms of commercial products and services, are forfeited to preserve estuarine fisheries habitat, economic reasoning is confronted by the following question: What is the optimum amount of estuary to maintain today, tomorrow and in the future for its various uses so that the stream of net social benefits from all uses of the estuary, present and potential, will be maximum?

A maximization of social welfare in the long term is the goal. Quite probably, society can afford the first yard or the first mile of estuarine tideland with much less loss in fish and wildlife than that involved in taking a subsequent segment; but to determine the point at which values foregone are greater than those gained is extremely difficult and demands a good knowledge of the working of the total ecosystem and its overall production possibilities and some informed estimates of the likely effect of changing one or another of its physical, chemical and biological characteristics.

"The National Estuarine Pollution Study" stated the valuation dilemma somewhat differently. "There are now (1970) about 5.5 million acres of important estuarine marsh and wetland habitat remaining in the estuarine zone of the United States. Perhaps each acre is not valuable by itself but the total habitat is irreplaceable."[12]

While the guiding principle to evaluation is erudite and socially sound—that net returns to society for all uses of the estuary should be the greatest attainable—there is difficulty in translating this principle into operational terms. The quantitative assessment of all the real cost created by a proposed action to alter estuarine conditions is almost unresolvable.[13]

There are, however, important practical considerations, tenets of economic good sense which can ensure that alternative courses of action do not unduly restrict future options. Useful proxies for the different pertinent measures supporting these tenets can be devised in quantitative or qualitative terms.

In deciding how much, if any, of an estuarine resource should be developed, the relative scarcity of the aquatic habitat, the numbers of flora, fauna and fish it supports, and other critical natural features must be identified. The functions that certain critical lands like wetlands serve in their natural state should be rigorously delineated and documented.[14]

The relative scarcity of the fisheries resource is an important consideration. It is demonstrable that estuarine resources provide aesthetic and unique services, in addition to the production of fin and shellfish which are increasing in economic value. Estuarine resources for fish production have appreciated in value as the demand for commercial and recreational fishing has responded to population growth and economic affluence and the diminution of estuarine habitats near large population centers.

A number of technological possibilities will moderate the impact of the other uses on fisheries habitat; water reuse and air cooling by diminishing the demands for the intake of fresh water and/or brackish water, desalting of brines and seawater, nuclear power, and improved water treatment argue a reasoned case for maintaining flexibility.

When the removal of aquatic habitat can cause irreversible consequences, there is a case for reasoned delay—time in which to demonstrate thoroughly the need for this estuary development and to acquire the knowledge that will allow its consequences to be predicted more reliably.[15] An "insur-

[12] "The National Estuarine Pollution Study," p. 289

[13] This is reimpressed if one asks what the loss to mankind is if by his actions a species of fin or shell fish is rendered extinct.

[14] The critical natural features theory was adopted in the decision of the Wisconsin Supreme Court: "The Just vs. Marinette County (4 ERC, 1941, Wisconsin, 1972) stands as an explicit judicial recognition that regulations preserving certain publicly critical features of land may be upheld without compensation despite great loss in economic development potential." See Environmental Quality, the fourth annual report of the Council on Environmental Quality, 1973, pp. 146-147.

[15] It is true that the filling of tidal marshlands, often termed irreversible, can be reversed by expenditure of large amounts of both time and money. It is virtually impossible to obtain an exact replica of the ecosystem as it was prior to disturbance. An irreversible condition for present purposes is defined as one for which the time or cost of the reversion is so high that in all likelihood it will not be undertaken.

ance premium" is paid to keep such an option open when the benefits of the development use are deferred. In some instances, these benefits may be considerable but so might the permanent loss of a critical segment of fishery habitat. These are sensitive trade-offs; the benefits should be identified and measured where possible.

Analyses ascertaining the fundamental biological relationships of the ecosystem show the relation of a part to the whole and are a necessary prerequisite to devising measures which are safeguards against irreversibility. In other words, interest centers on what happens to the whole when a part of the ecosystem is modified or converted to other than its natural use.

Investigation of the relation of the part to the whole (of the role of specific estuarine habitat such as tideland to the overall aquatic environment) presents the biologist and ecologist with a very complex problem—one which is further complicated by compartmentalized planning studies which frequently ignore or deemphasize these interrelationships.

The system's approach is violated when agencies responsible for estuarine management are requested to evaluate a development. In many instances, these agencies do not have the choice of proposing an alternative to the development they have been asked to evaluate, nor do they have the research capability and manpower to investigate and sponsor such alternatives. Appropriate tenets of evaluation are of little use in estuarine management unless they receive institutional sanction and are activated by competent technical and management staff.

The present composition of research staffing in many agencies, especially water resources and fish and game, is largely oriented to a preponderantly engineering viewpoint even to the assessment of social values. Biological, ecological, and social viewpoints should not be subservient to that of engineering, efficiency or the constructionist: a partnership is urgently required, and this will mean adequate, competent staffing in these three categories.

The type of research advocated above and the employment of sound tenets of evaluation would serve to unmask "the tyranny of small decisions" where one decision taken at a time is relatively unimportant but given time and additional decisions the system is completely altered.[16] The cumulative effects in the future of many small irreversible commitments of the remaining 5.5 million acres of estuarine marsh and wetland habitat (1970) were the special concern of the "National Estuarine Pollution Study."[17]

The relative scarcities of the fishery resource itself and the particular fishery habitat are not the only practical considerations. The availability of substitutes and substitute sites for the products to be obtained from estuarine resources is a basic consideration. Are there other opportunities including technical possibilities for the development of products which even though they make the product more costly are not so costly in terms of depleting biological resources and aesthetic qualities?

The economic reasoning in following this tenet of the evaluation credo may be illustrated from an actual case study for the San Francisco Bay. Projected dredging and retrieval of aggregate (at low operations costs) from an extensive and shallow aggregate source such as the Potato Patch Shoals, immediately outside the Golden Gate, would very likely jeopardize the support for the local supply of crabs in the bay area. In such a situation, the following questions should be answered. For what purposes is the aggregate required? Is it to be used for concrete construction or for bay fill to create additional home and factory sites to further accelerate the diminution of estuarine habitat? If the former, are there other sources of aggregate; if the latter, what is the relative scarcity of homesites in the vicinity? In other words, have all the opportunities for the projected homesites or supply centers for aggregate for construction or fill been carefully explored? What additional costs are involved in selecting alternative sites both for aggregate and for homes or factories? These costs could prove to be not so great when compared with the benefits flowing from an appreciating renewable resource.

On the other side of the ledger, what would be the economic repercussions of losing a valuable local seafood resource? The impact of losing the local crab resource is not measured solely in the loss of income to fishermen who forfeit all or part of their customary livelihood. There are the indirect or neighborhood effects which must be accounted for. Fishermen's Wharf, a traditional center for seafood, could experience a decline in expenditures by both local clientele and tourists, with further repercussions in the business sector. The costs enumerated are real and cannot be omitted in the tally of social costs occasioned by the loss of a vital part of any fish support system.

In summary, many estuaries, in providing healthy fishery habitats, are appreciating assets and some development decisions are irreversible. And although current evaluation methods do not adequately quantify all social values, even a reasonably accurate picture cannot be obtained of the social costs and benefits of maintaining or improving estuarine fish production unless economic reasoning is fully employed to provide insight to alternative courses.

[16] Kahn, A. E. 1966. The Tyranny of Small Decisions: Market Failures, Imperfections, and the Limits of Economics. Dkylos. 19 (1): 23-47.
[17] "The National Estuarine Pollution Study," p. 289.

VALUE OF COMMERCIAL FISHING: INDICATOR OF SOCIAL IMPORTANCE

While many extramarket uses of estuarine habitat remain unmeasured in strict quantitative market terms, the commercial catch can be valued in different economic terms—its value to the fishermen, to the processor, or the final price paid by consumers. In all instances, whatever value is adopted it is but one indicator, an incomplete one of the worth of estuarine fisheries habitats.

In broad terms, estuarine fisheries habitats are highly valuable and significant assets; approximately 65 percent of all commercial fish species and practically all of the sports fish species are dependent upon the estuarine zone for one or more phases of their life development.

The estuary is the ultimate source of food for some continental-shelf species and most marine predators, including tuna.[18]

The estuary is then the vital support system to a valuable renewable resource, fish, which supplies a significant portion of the edible protein consumed by man. In addition, the estuary is an important source of fish meal, a high protein feed for another important source of edible protein, poultry and swine.

Two-thirds of the total landed value of commercial fish and shellfish has been estimated as derived from estuarine-dependent species.[19] Other estimates cite the annual landed value of commercial fisheries as being 75 percent estuarine-dependent or associated fish.[20] Regionally the values vary; in the Gulf of Mexico, estuarine-dependent resources supply 90 percent of the commercial catch.[21]

The 1972 commercial catch was valued at $704 million (see Table 2). Estuarine-dependent species provided $470 million, a 57 percent increase in the landed market value of $300 million in 1965. At an interest rate of five percent, the capital investment required to return $470 million annually would be approximately $9.4 billion.[22] This provides an estimate of the importance of the estuarine fisheries habitats for the United States commercial catch.

Another measure of the economic importance of the commercial fishing industry is the income generated by its demand for basic inputs such as boats and equipment and supplies used in catching and landing fish. Sizable income would be lost to these suppliers and manufacturers if the commercial fishery were to close.

It has been estimated that the multiplier associated with commercial fish harvesting is 2.96. This means that $2.96 of economic activity (including supportive industries, expenditures on fuel, equipment, wages, et cetera) is generated from each dollar of additional income to fishermen.[23]

Estimates of future market demand, coupled with the probable scarcity of future supplies, indicate a continuation of rising values for estuarine-dependent fish. Estuaries as fishery habitats are rapidly appreciating national assets. Figure 2 illustrates the increase in future market demand, which is projected to double by the year 2000.

Further, income elasticities for different fishery products attest to increasing demands for finfish and crustaceans basically dependent upon an estuarine environment. Income elasticities of demand for fish products show the change in consumption of the product in response to a change in consumer income. Income elasticities for some important estuarine fish have been estimated as follows: lobster, 2.1; shrimp, 1.8; fresh and frozen salmon, 1.6; crab, 1.3; and groundfish (flounder being representative), 1.2.[24] Income elasticities are indicative of future consumption. For example, a 10 percent increase in per capita income would be accompanied by an 18 percent increase in the quantity of lobster consumed, a 16 percent increase in the quantity of shrimp consumed, and a 16 percent increase in the quantity

Table 2.—Fisheries: Quantity and value of catch 1930-72[1]

Year	Total	For human use	For industrial products[2]	Value (million dollars)	Average price per pound (cents)
	(million pounds)				
1930	3,224	2,478	745	109	3.4
1940	4,000	2,675	1,325	99	2.4
1950	4,901	3,307	1,594	347	7.1
1960	4,942	2,498	2,444	354	7.2
1965	4,777	2,587	2,190	446	9.3
1968	4,160	2,347	1,813	497	11.9
1969	4,337	2,321	2,016	518	12.1
1970	4,917	2,537	2,380	613	12.5
1971	4,969	2,400	2,569	643	12.9
1972	4,710	2,310	2,400	704	14.9

[1] Does not include the value of fish harvested by foreign vessels off the U.S. coast.
[2] Manufactured into meal, oil, fish solubles, homogenized condensed fish, and shell products, and used as bait and animal food.

Source: U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States: 1973, 94th edition, Washington, D.C., 1973, Table No. 1072, p. 635, citing U.S. National Oceanic and Atmospheric Administration, Fishery Statistics of the United States, annual.

[18] Estuarine dependence is based on whether one or more phases of the species' life cycle is spent in estuaries. The estuarine dependence of important sport and commercial fish is shown in Table IV.2.1 of The National Estuarine Pollution Study.
[19] "The National Estuarine Pollution Study," p. 151.
[20] "National Estuary Study," v. 5, Appendix E, p. 16.
[21] McHugh, J. L. November 1968. "Are Estuaries Necessary?" Commercial Fisheries Review, 30 (11): 37-45.
[22] The value of tidal marshes on the east coast has been deduced as $2500 to $4000 per acre per year; when these annual social values are income capitalized at five percent interest, the estimated total social values are $50,000 to $80,000 per acre. Gosselink, J. G., E. P. Odum and R. M. Pope. 1974. The Value of the Tidal Marsh. Pub. No. LSU-SG-74-03, Center for Wetland Resources, Louisiana State University, Baton Rouge.
[23] "National Estuary Study," v. 5, Appendix E. p. 17.
[24] Ibid.

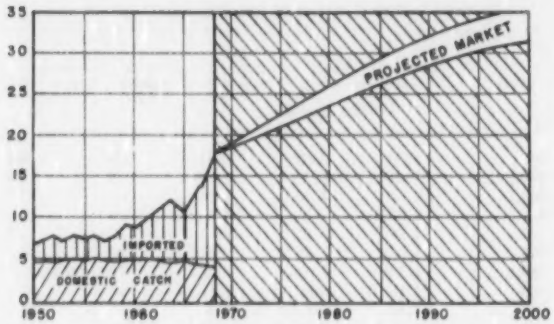

FIGURE 2.—U.S. market for fishery products. Source: U.S. Department of the Interior, Fish and Wildlife Service. March 26, 1970. National Estuary Study 5, Appendix F. Washington, D.C.: 17.

of salmon consumed. The consumption of all of the species indicated above increases more than proportionally with income rises.

IMPUTED VALUES OF SPORT FISHERIES: ANOTHER USEFUL INDICATOR

Nearly every sport fish species is dependent upon the estuarine zone for one or more phases of its life cycle.[25] It is concluded that "saltwater sport fishing is far more closely related to estuaries than commercial fisheries.[26] The estuarine zone offers a great diversity of environment and species to sport fishing. For this and other reasons, sport fishing has become an increasingly popular and economically important aspect of estuarine fisheries use.

By the year 2000 sport fishing is expected to increase by some two to two and one-half times in saltwater and the Great Lakes.[27] All indications point to sport fishing's becoming an increasingly valuable use of estuarine fisheries habitats. This value lies not only in the value of the actual fish caught, but in the social value of recreational activity, as well as in the great variety of related goods and services generated by the fishing activity. While dollars can be imputed to estuarine sport fishing activities, and a number of useful refinements have been made in the art of economic measurement, as yet the joint-products dilemma has not been resolved satisfactorily. These values, computed either by applying an administrative price for user days or by using travel-cost imputation are useful to give an order of magnitude assessment for a specific activity in a specific location but are inadequate to encompass all the joint services—values stemming from the estuarine environment as they relate to sport fishing.[28]

Not all uses of estuarine resources compete with fishery production. There is a degree of compatibility between fish production and the discharge of nutrients or heated water.

The assimilative capacities of the estuarine zone allow limited quantities of non-toxic waste to be assimilated by the system. Small quantities of waste can even be helpful to fishery productivity by supplying necessary nutrients in sufficient quantities.

The economic contribution made by the assimilative capacity of five eastern estuaries (Delaware, East, Hudson, James and Potomac) was estimated to be $5,903,000.[29] This value relates only to a miniscule part of the total chemical and biochemical processes occurring within these estuaries. The environmental services in toto performed by an estuarine zone defy meaningful calculation. The full extent of their value would become more comprehendable if it were ever necessary to replace or substitute the complete range of these services.

IMPORTANT SOCIAL AND ECONOMIC TRENDS

Changing economic and demographic patterns have exerted developmental pressures which are the most significant factors affecting the estuarine fishery habitat. Certain trends with implications for degradation of the estuarine environment are projected to continue; population will grow rapidly in coastal counties, with expansion in the urban-suburban areas, and ports and the volume of commerce will expand as these economic bases grow. Projected activities in the estuarine zone, consequently, will play a decisive and increasing role in determining the future productivity of the fishery habitat.

Two broad sources of degradation of fishery habitat are foreseen as resulting if these pressures are not suitably countered by informed management.

The first source is constituted of direct pollution of nutrients and toxic materials from municipal and industrial wastewater discharges and dumping; agricultural runoff carrying pesticides, salt, nutrients and silt; thermal heat and waste from power develop-

[25] "The National Estuarine Pollution Study," p. 115.
[26] "Economic and Social Importance of Estuaries," p. A-22.
[27] "The National Estuary Study," v. 5, Appendix E., p. 32.

[28] The annual net benefits for recreational fishing in San Francisco Bay for 1966 and 1980 were estimated to be $9 million and $15.5 million respectively. An administratively adjudged user day value varying from $.50 to $1.50 per day was applied to fishing days to impute net benefit. See Delisle, G. October 1966. Preliminary Fish and Wildlife Plan for San Francisco Bay-Estuary. Prepared for the San Francisco Bay Conservation and Development Commission: 94.

[29] Economic and Social Importance of Estuaries. April 1971. Estuarine Pollution Study Series 2, Environmental Protection Agency, David Sweet, Project Director: 55-56. The dollar value was calculated as follows. The pounds of biochemical oxygen demand (BOD) that had to be removed to achieve a one mg/l increase in minimum dissolved oxygen was estimated. The cost of removing a pound of BOD was assessed at $0.04.

ments; storm water runoff and discharges from other diffuse sources; spills and leakages of hazardous materials into coastal zone, and pollution within the estuary from dredging, channeling and other alterations. The second source can occur through the nonpollutional damage of the fishery habitat through landfills, overfishing, and even depletion of marine life by excessive collection and study. Degradation of the latter type is occurring in some parts of the tidal zone of California.

The impact of the waste in all media—water, air and solid—from point and diffuse sources varies greatly from estuary to estuary depending upon the combined concentrations that directly or indirectly find their way into a specific estuary. The geophysical structure of the estuary, the physical processes of advection and diffusion, variations in freshwater inflow and many other major physical processes which at present are only qualitatively understood determine the mixing of these various forms of wastes at the freshwater-saltwater interface and throughout the estuarine area.

The characteristics that allow an estuary to concentrate and reuse nutrients that sustain fish productivity also make the estuary a concentrator of pollution and waste.[30]

Compounding the effects of waste concentration is the vulnerability of estuarine residents. Many of the estuarine organisms are living near the limit of their range of tolerance and any further alteration, regardless of how slight it may be, has the potential of excluding an organism from the estuary.[31] Furthermore, the deposition of most of these wastes occurs offshore in the shallow areas of the estuaries, areas of highest productivity and necessary to the estuary for the production of oxygen.

Figure 3 depicts the fate and distribution of estuarine pollutants; only the elementary processes involved in what is a highly complex phenomenon are indicated.

An appraisal of the impacts of wastes on fishery productivity in different estuaries is a complicated task and cannot be attempted in this paper for reasons already given. It is possible, however, to identify those intensifications of use of the estuarine resources which are compounding and will compound the difficulty of maintaining fishery resources.

[30] Duke, T. W. and R. R. Rice. 1967. Cycling of Nutrients in Estuaries. Proceedings of Gulf and Caribbean Fisheries Institute, (19):59:67. Pomeroy, L. R., R. J. Reimold, L. R. Shenton and R. D. H. Jones. 1972. Nutrient Flux in Estuaries. Nutrients and Eutrophication, edited by G. E. Likens, American Society of Limnology and Oceanography, Special Symposium 1:274-296; Scheiske, C. L. and E. P. Odum. 1961. Mechanisms Maintaining High Productivity in Georgia Estuaries. Proceedings of Gulf and Caribbean Fisheries Institute, 14:75-80. (The levels of phosphorus in estuarine water have been shown to be 10 to 40 times higher than in the river-water flowing into the estuary.)

[31] Odum, William E. 1970. Insidious Alteration of the Estuarine Environment. Transactions of American Fishery Society, 4: 836-845.

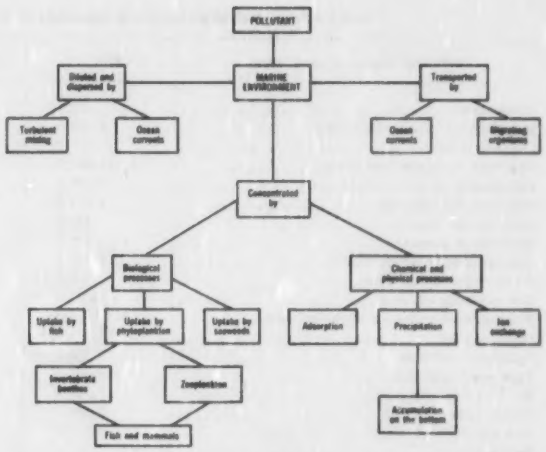

FIGURE 3.—The fate and distribution of estuarine pollutants. Under favorable conditions, the pollutants are diluted, dispersed, and transported by turbulent mixing, ocean currents, and migrating organisms. The mixing is often restricted so that high concentrations of pollutants can exist in local areas. In addition, biological, chemical, and physical processes concentrate pollutants and lead the pollution back to man. Source: Patterns and Perspective in Environmental Science. Report prepared for National Science Board, National Science Foundation. 1972. Figure VIII–8, p. 245.

The future aquatic environment will be greatly influenced by the success of water quality control programs not only as they relate to the estuary proper but to the freshwater streams flowing into the estuaries.

MUNICIPAL AND INDUSTRIAL WASTE DISCHARGES

Since increases in population are usually accompanied by increases in the loads of municipal and industrial wastes, discharging and dumping of these wastes, (although greatly reduced from the levels of the late 1960's) must be counted a major problem in most estuarine zones in the populous areas of the nation.

Population in the estuarine areas grew by 78 percent from 1930 to 1960 while national population grew by only 46 percent. In 1970, 33.7 percent of the United States population resided in the estuarine economic areas. The population residing in these areas as a percent of the national total is projected to grow to 34 percent by 1980, 36.9 percent by 1990, and 38.8 percent by 2000, when 107 million people out of 275 million will be living in or close to estuarine areas.

The projected populations for different estuarine

Table 3.—Estimates and projections of population in the estuarine economic region and individual area (in thousands)

Individual estuary economic areas	1950	1960	1970	1980	1990	2000
Maine coast	471.7	499.7	531.5	576.7	633.6	688.2
Massachusetts—Rhode Island coast	4,355.4	4,798.3	5,194.3	5,729.2	6,390.6	7,958.2
Connecticut coast	761.2	934.9	1,057.0	1,184.8	1,343.9	1,492.2
New York—northeast New Jersey	13,593.6	15,603.5	17,376.5	19,114.4	21,061.0	23,022.3
Philadelphia—New Jersey—Delaware	4,399.3	5,320.8	5,939.9	6,661.5	7,567.1	8,505.8
Maryland—Virginia coast	4,473.0	5,739.5	6,812.8	8,023.3	9,573.3	11,172.1
North Carolina coast	447.1	511.7	529.0	546.1	582.7	623.0
South Carolina coast	374.8	466.2	503.2	539.0	595.7	652.2
Georgia—eastern Florida coast	1,432.5	2,637.8	3,698.7	4,699.3	5,752.5	6,941.1
Southern Florida gulf coast	547.7	1,058.7	1,369.0	1,663.1	1,931.0	2,302.7
Central Florida gulf coast	98.0	126.5	134.2	150.2	171.0	198.1
Mississippi—Alabama—west Florida coast	563.0	818.5	977.0	1,135.3	1,363.3	1,603.2
Louisiana coast	1,177.8	1,535.3	1,814.7	1,974.4	2,168.6	2,930.0
Texas north gulf coast	1,324.7	1,900.8	1,206.7	2,710.4	3,304.1	4,026.1
Texas south gulf coast	441.5	563.8	635.6	704.1	792.3	878.2
Southern California coast	5,233.5	8,224.9	10,826.2	13,586.9	16,906.1	20,331.0
Central California coast	2,944.2	3,972.6	5,084.6	6,280.3	7,696.9	9,150.2
Northern California coast	78.0	122.7	151.0	188.1	230.1	273.8
Oregon coast	1,091.4	1,276.8	1,389.3	1,602.7	1,849.6	2,087.7
Washington coast	1,493.7	1,837.3	2,165.5	2,536.8	2,972.6	3,444.1
Estuarine economic region total population	45,302.1	57,946.2	68,396.9	76,606.7	92,940.0	106,900.3
Total U.S. population	151,370	179,320	203,210	225,000	252,000	275,000
Percentage of U.S. population in estuary economic areas	29.9%	32.2%	33.7%	34.0%	36.9%	38.8%

Source: Office of Business Economics, Regional Economics Division, and U.S. Bureau of the Census Statistical Abstracts of the United States, 1973.

economic areas are shown in Table 3.[32] In addition, these populous coastal counties, while they contain only 15 percent of the land area, have 40 percent (1969) of the manufacturing activities within their boundaries.

Information on the effects of municipal and industrial loads and their treatment on water quality are not readily available for different estuaries, although sampling of water quality parameters in a number of estuaries is part of the ongoing effort. Overall water quality trends have been assessed for the nation, but the water quality trends as reported are insufficient indicators of the effects of changing conditions for the biological communities in estuaries.[33] They offer no high resolution of the status of water quality for fish production, but provide useful information on water quality; estuaries are natural sinks for water pollutants so that the quality of inflowing river water is of consequence to biological communities in estuaries.

In 1970, cleanup efforts to improve water quality under the federal-state program established by the 1965 Water Quality Act were appraised as only holding the line on common organic pollution. "The effects of increased treatment had been virtually cancelled by larger wasteloads. Other forms of water pollution such as phosphates and nitrate nutrients were on the rise. Fish kills, beach closings, algal growths, oily scums, and odors were still prevalent. Sporadic upgrading of municipal treatment plants were often more than offset by nearby industrial effluents. In other cases, cleanings of industry were offset by increasing municipal discharges."[34]

The 1972 amendments to the comprehensive Federal Water Pollution Control Act were designed to correct these inadequacies, and set a course for a sustained water quality improvement program.

For the period to 1977 the objective of the act, "to restore and maintain the chemical, physical and biological integrity of the nation's waters," has been interpreted as requiring standards which will protect indigenous aquatic life and permit secondary contact recreation such as boating and fishing. A quality of water which will protect aquatic life is considered adequate to ensure other uses such as public water supply, agricultural industrial use, and navigation.[35]

To achieve the 1983 interim goal of Sec. 101(a) of the act, providing for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water, EPA has proposed water quality criteria defining maximum limits of acceptability

[32] The estuarine zone economic region includes the coastal counties plus a few noncoastal counties included as part of estuarine zone Standard Metropolitan Statistical Areas. Recent projections show U.S. population to be slightly lower than those given in Table 3. See U.S. Department of Labor, Bureau of Labor Statistics, Kutscher, Ronald. December 1973. Projections of GNP, Income Output and Employment. Monthly Labor Review, 96: 3-42.

[33] EPA National Water Quality Inventory, Report to Congress, Washington, D.C., U.S. Government Printing Office. The major waterways sampled are shown in Appendix Table 2.

[34] Environmental Quality, The Fourth Annual Report of the Council on Environmental Quality, September 1973: 168; Environmental Quality, the Second Annual Report of the Council on Environmental Quality, 1971: 217-221.

[35] P. L. 92-500, Sec 101(a). See also EPA Water Quality Strategy Paper, March 15, 1974, p. 28.

for chemical and physical constituents in United States waters.[36] These criteria are based on recommendations of a National Academy of Science report and reflect current knowledge of the identifiable effects of pollutants on human health, fish and aquatic life, plants, wildlife, shorelines, and recreation; concentration and dispersal of pollutants; and the effects of pollutants on biological community diversity, productivity and stability, including factors affecting rates of eutrophication and sedimentation.[37]

The National Water Quality Inventory allows an overview of water quality trends from 1963 to 1972 for 23 waterways (a total of 35 major reaches) draining 70 percent of the Nation's land. It has furnished some evidence that nutrient levels increased. "In 84 percent of the reaches, phosphorus and phosphate (readings exceeded) reference levels associated with potential eutrophication. . . . 54 percent of the reaches showed increased phosphorus levels in 1968–72 over the previous years (1963 to 1968). Nitrate levels also increased in 74 percent of the reaches examined. . . . other pollutants with high levels were phenols that can affect fish palatability and suspended solids which interfere with some aquatic life processes."[38] The major rivers included in the water quality analysis and the results are set out in Appendix Table 2 and Appendix Tables 3 and 4, respectively.

Progress in the last five years, 1968 to 1972, is evident for oxygen demand and bacteria. The data available for heavy metals and pesticides showed that drinking water levels for cadmium, lead, mercury, iron, and manganese were exceeded by one or more samples collected over the 1968 to 1972 period in more than half the reaches examined; nine pesticides were found to exceed reference levels in more than half of the reaches.[39]

One indication of the extent and severity of water pollution at present is that to achieve the water quality target for 1977 approximately 1,600 of the 3,100 water quality reaches identified will have to go beyond 1977 technology-based effluent standards.[40]

Projections to 1985 of the state of water quality have been made in an attempt to assess the likely impact of measures taken under the Federal Water Pollution Control Act. A comparison is made of the "controlled" effluents, the levels expected to result pursuant to the standards and regulations established under current water control legislation, and

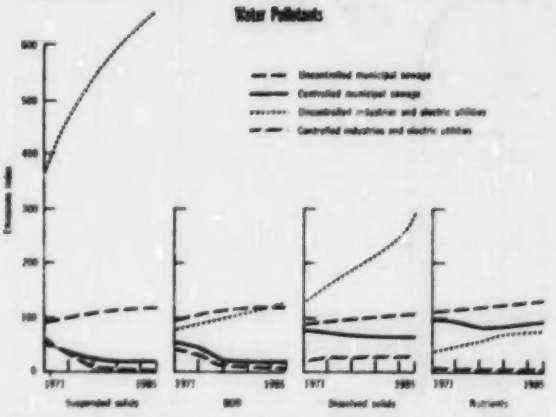

FIGURE 4.—The base case of seas: generation of pollutants, by sector. (1971 emissions = 100). Source: Council on Environmental Quality. Environmental Quality. The Fifth Annual Report: 295.

the "uncontrolled" effluents if no pollution abatement was undertaken. The result of the analytical tool SEAS, Strategic Environmental Assessment System, is shown in Figure 4.[41]

Municipal sewage treatment effluents are projected to account for virtually all of the "controlled" nutrients and 70 percent of the dissolved solids. Under the 1972 amendments to the Federal Water Pollution Control Act (PL 92-500), discharged waste loads from municipal and major industrial sources (including electrical utilities) then can be expected to decrease significantly with implementation of a responsive wastewater management program.

National projections of water quality, however reliable and illustrative, are only indirectly meaningful for specific estuaries. Projected waste loads from municipal and industrial sources for the San Francisco Bay place in better perspective the water quality management problem that will confront many "urbanized estuaries."

As in other estuarine zones, an increase in the degree of treatment and improvement in operations in recent years has kept waste loads discharged to San Francisco Bay essentially constant although population and industrial activities have steadily increased. Diffuse waste sources such as storm runoff from urban and non-urban areas, however, are projected to increase as the San Francisco Bay region continues to grow. Graphical comparisons of the waste loads for BOD, heavy metals, and nitrogen from point and diffuse sources in Figures 5, 6, and 7 point to the necessity to develop a manage-

[36] EPA, Water Quality Criteria, 1973.
[37] National Academy of Sciences, Water Quality Criteria, 1972.
[38] Results of the National Water Quality Inventory conducted by EPA are summarized in Environmental Quality, 1974, the Fifth Annual Report of the Council on Environmental Quality: 282-288.
[39] Ibid.: 286-287.
[40] Ibid.: 142. See also EPA Water Quality Strategy Paper, March 15, 1974: 28.
[41] Environmental Quality, Fifth Annual Report: 297.

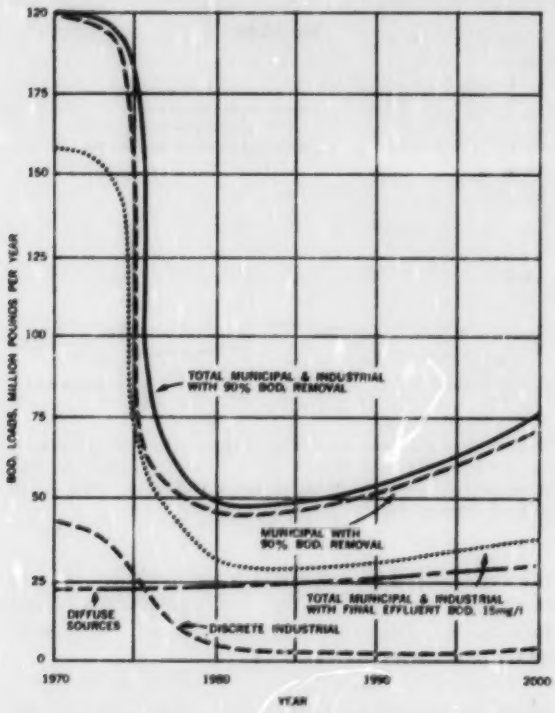

FIGURE 5.—Projected BOD loads discharged to San Francisco Bay.

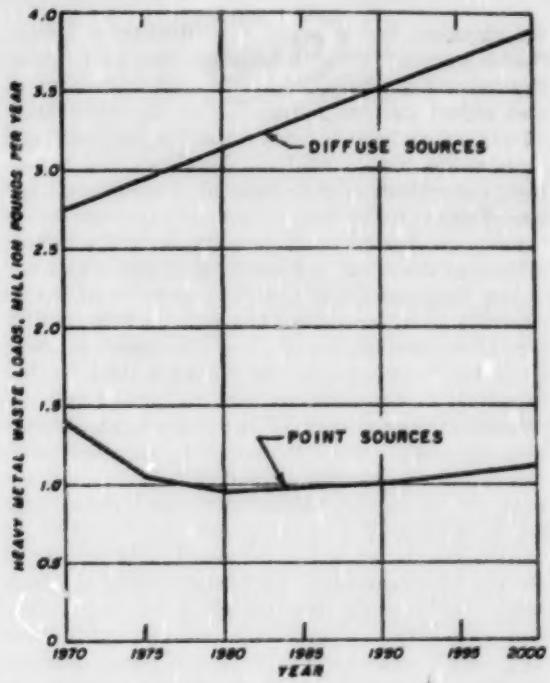

FIGURE 6.—Projected heavy metal loads discharged to San Francisco Bay.

ment system to contain discharges from diffuse as well as from point sources.[42] The projected increase in the loads of heavy metals, oil and grease, nitrogen, phosphate, and pesticides and in some estuaries polychlorinated biphenyls from diffuse sources also are sufficiently great to alert management to their implications for the retention of productive fishery habitat.[43]

The importance of runoff in degrading water quality cannot be dismissed in any plan for comprehensive water quality management in the estuarine zone. In urban estuarine areas runoff from storms can contribute a major portion of the water pollution load. In the intense discharge during storms from 94 to 99 percent of the BOD load can be contributed by runoff and bypasses.

The storm runoff from a moderate-sized city has been assessed as contributing a heavy load of metals—100,000 to 250,000 pounds of lead and 6,000 to 30,000 pounds of mercury each year.[44]

The unabated discharge in storm water of heavy metals, given the toxicity of these metals, is a cause for concern for the "urbanized estuaries." The treatment of municipal and industrial discharges alone in the future will in most instances not be sufficient to insure a productive fishery habitat, one in which the end use—edible fish—is not denied to man because of high levels of contamination from harmful and toxic substances.[45]

Storm water runoff is but one source of the toxic

[42] These figures appear as Figures 7, 8, and 9 in Development of a Water Quality Control Plan, San Francisco Bay Basin, Workshop, March 5 1974, California State Water Resources Control Board, Sacramento, California: 12. Loads of heavy metals were calculated from available data on concentration of cadmium, chromium, copper, lead, mercury, nickel, and zinc in existing municipal and industrial wastewater and in urban and non-urban storm runoff.

[43] In July 1973, EPA designated 12 chemicals used in manufacturing as toxic water pollutants, including cadmium, mercury and polychlorinated biphenyls, as well as the pesticides aldrin, dieldrin, endrin, DDT and its derivatives DDE and DDD. The pesticide compound toxaphene was also included. Other metals currently being studied for possible inclusion on the list include arsenic, selenium, chromium, lead, beryllium, and nickel.

[44] Total Urban Water Pollution Loads: The Impact of Storm Water, (PB-231/730) is available from National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22151. In July 1973 EPA designated cadmium and mercury used in manufacturing as toxic water pollutants. EPA is currently developing effluent standards governing the discharge of these two heavy metals. In addition, EPA is studying arsenic, selenium, chromium, lead, zinc, beryllium, and nickel for possible inclusion on the list of toxic pollutants. See 38 Federal Register 2434 (1973), 40 CFR 129. Toxic pollutants are defined as those which "cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction) or physical deformations in such organisms or their offspring." PL 92-500, Stat. 816, 1972.

[45] The minamata disaster reimpresses the gravity of high levels of toxic forms (mercury). The effects of low-level exposure over long periods—genetic, mutagenic and tetragnicity, et cetera—are also legitimate reasons for concern.

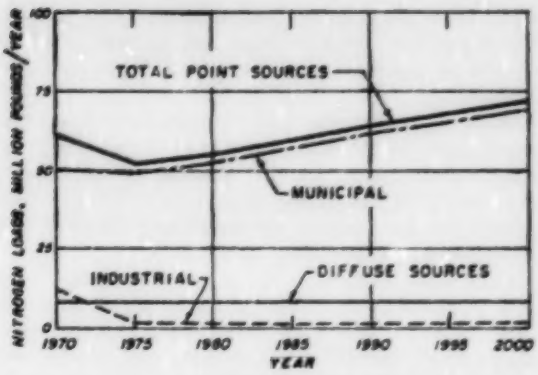

FIGURE 7.—Projected nitrogen loads discharged to San Francisco Bay.

trace element contaminants (principally heavy metals) and hazardous and toxic chemicals which are distributed by complex pathways encompassing essentially all media and their associated ecosystems. In estuaries the biological conversion to even more toxic forms, e.g., organometallics and accumulation in the aquatic ecosystems and sub-strates, underscores the importance of this pollution problem for estuaries. The potential hazard of certain trace elements is demonstrated by the concentration factor for shellfish (see Table 4).

Other sources of trace element emissions to the environment are reasonably well identified; quantitative estimates are available for air emissions from different industries and the trace element contents of wastewater from lead-zinc processing have been calculated. Sludges and solid residues (tailings) also constitute a source of trace element contaminants

Table 4.—Concentration factors for the trace elements composition of shellfish compared with the marine environment

		Encroachment factors		
		Scallop	Oyster	Mussel
Silver	Ag	2,300	18,700	330
Cadmium	Cd	2,260,000	315,000	100,000
Chromium	Cr	200,000	60,000	320,000
Copper	Cu	3,000	13,700	3,000
Iron	Fe	291,500	68,200	196,000
Manganese	Mn	55,500	4,000	13,500
Molybdenum	Mo	90	30	60
Nickel	Ni	12,000	4,000	14,000
Lead	Pb	5,300	3,300	4,000
Vanadium	V	4,500	1,500	2,500
Zinc	Zn	28,000	110,300	9,100

Source: Ketchum, B. H., editor. The Water's Edge: Critical Problems of the Coastal Zone. 1972. The MIT Press, Cambridge, Mass., Table 7.2: 150; based on Brooks, R. R. and M. G. Rumsby. 1965. The Biochemistry of Trace Element Uptake by New Zealand Bivalves. Limology and Oceanography 10:521-527.

in estuaries unless adequate storage or disposal is practiced.

There are other major sources of trace element contamination to water and land receptors in estuarine areas, notably automotive exhaust (lead), leaching from municipal landfills, and incinerator and land disposal of sewage sludge from municipal wastewater treatment.[46] Agricultural chemicals contribute to heavy metal loads as nonpoint water pollution, especially mercury, copper, zinc, cadmium, manganese, and chromium.

The setting of air and water quality standards for the various trace elements related to point and diffuse sources of contamination requires the identification of sources, forms of pollutants, pathways, and the effects of each substance on the biological communities in estuaries.

Effluent guidelines have been promulgated by EPA for some 29 industries up to June 30, 1974 (see Appendix Table 5). Nevertheless, there is urgent need for additional effluent limitation guidelines, for EPA has identified a total of about 180 industrial subcategories and 45 additional variances as requiring distinct effluent standards.

In urban storm water discharges, PCB's and pesticides have been identified as significant components.[47] Like the heavy metals, hazardous chemicals —diethyl-stilbestrol, thalidomide, DDT, polychlorinated biphenyls, vinyl chloride, pesticides, and phthalic acid esters—find their way into the estuarine environment along a variety of incredibly complex pathways from many sources.[48]

Of all chemical classes, pesticides would appear to pose the most difficult future pollution problem since sources are diffuse and spread over millions of acres in the 18 principal water regions of the nation. Pesticide use in urban areas has increased. The widespread presence and buildup of persistent pesticides in water and in fish and marine mammals are well documented. These characteristics make pesticides and other hazardous and toxic substances a major problem to resolve for the protection of the health of man as well as for estuarine biological communities.

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[46] Young, D. R. et al. February 1973. Source of Trace Metals from Highly Urbanized Southern California to the Adjacent Marine Ecosystem. Proceedings of a conference on Cycling and Control of Metals, sponsored by EPA, NSF and Battelle: 21-30. On December 6, 1973, EPA promulgated regulations limiting the lead content of gasoline; allowable level of lead is reduced to an average of 1.7 grams of lead per gallon in 1975, and 0.5 grams of lead per gallon in 1979. This is the most significant and controllable source of lead exposure. 38 Federal Register 33734, (1973).

[47] Sartor, J. D., and G. B. Boyd. November 1972. Water Pollution Aspects of Street Surface Contaminants. 76-81 EPA-R2-72-081.

[48] The pesticides aldrin, dieldrin, endrin and DDT and its derivatives DDE and DDD were designated toxic water pollutants by EPA in July 1973. Sevin, chlordane, lindane, methyl parathion and parathion are currently being studied for possible inclusion in the list.

PETROLEUM LEAKAGE IN ESTUARINE ENVIRONMENTS

Natural energy demand, even if stringent conservation measures are in force, is expected to double between now and 1985. The development of new energy technologies such as coal gasification, coal liquefaction, oil, shale and tar sand processes, and nuclear reactors is likely to have effects on aquatic ecosystems in estuaries some 10 years in the future. However, the impact of the increase in thermal power stations could be expected to occur earlier while the increase in domestic offshore oil production and in oil imports can be expected to aggravate oil leakage into the coastal zone.[49]

Within the next 10 years the United States' heavy dependence on oil and gas to meet its energy demands is not likely to diminish. In 1972, oil and gas accounted for nearly 78 percent of U.S. energy consumption. Expanded total energy needs were forecast to require 28 million barrels of oil per day in 1985, nearly twice the consumption in 1970. Other forecasts before the oil embargo indicated that oil imports would likely increase to 15 to 20 million barrels per day by 1985.[50]

National steps taken to reduce dependence on foreign oil imports—federal legislation authorizing construction of the trans-Alaska pipeline, expansion of the leasing program for the outer continental shelf, and a proposal to authorize construction of deepwater ports—all have implications for increased leakage of oil and petroleum products into the coastal environment of states adjacent to offshore oil wells or that have large refineries.[51]

Approximately 60 percent of U.S. refining capacity (seven million barrels per day, 1972) is concentrated in the four coastal states of Texas, Louisiana, California, and New Jersey. Production of oil from offshore reservoirs (over 8000 offshore wells in the Gulf of Mexico alone) is expected to reach 30 to 40 percent of total oil and gas production by the early 1980's.

Accelerated imports increase the risks of potential discharges from intentional or accidental tanker spills outside or in port (estuary), while increased offshore production adds to the potential hazard of major oil spills from blowouts.[52] Coastal areas must provide the space for receiving increased quantities of oil carried by pipelines and tankers as well as additional refineries.

Annual incremental spill volumes in U.S. coastal areas have been estimated for different levels of daily oil imports. In the absence of superports and assuming continued deterioration of the U.S. energy supply posture, approximately 800,000 barrels of oil could be spilled by 1983.[53]

Petroleum leakage to the ocean and coastal zone is not confined to tanker spills or blowouts from offshore wells. There are many small chronic injections of oil and oil products into the marine environment near shore. Injections of oil and grease result from sewage discharges and storm sewers, filling station washdown operations, transportation operations, and other domestic and industrial losses, including hydrocarbons leaked from outboard motors.[54]

It has been concluded that petroleum from production, refining or transportation has penetrated the marine food chain; however, an assessment of the biological effects of petroleum from different sources on the metabolism of organisms has not been made.[55] Little is known about the long-term effects of oil in an estuarine environment. Spills and leaks of oil cause a number of adverse effects in the estuarine environment, not all of which are well understood.

Oil and components of oil can be lethal to organisms or inhibit normal feeding. The effects of oil pollution of shoreline in estuaries depend partly on the nature of the oil and partly on the means by which it reaches the shore. The coating of rocks, beaches, marshes can cause significant plant and organism mortality. The nearshore marshes and

[49] The problems of energy supply and the impacts of heat disposal from power plants in the coastal zone are discussed in Chapters 5, 7 and 8 of the Water's Edge: Critical Problems of the Coastal Zone, edited by Bostwick H. Ketchum, The MIT Press, Cambridge, Massachusetts, and London, England. A major study to investigate the potential environmental effects of offshore nuclear power plants was initiated by the Council of Environmental Quality in 1973. Publication of this study is expected in early 1975.

[50] Joint Committee on Atomic Energy, 93rd Congress, 2nd Session. 1974. The Nation's Energy Dilemma.

[51] Hypothetical drilling sites and development locations for the Atlantic outer continental shelves are offshore to Massachusetts, Rhode Island, New Jersey, New York, Delaware, South Carolina, Georgia, and Florida. Over 17,000 wells have now been drilled in waters off the U.S. coast. The potential impact of outer continental shelf oil development depends in part on where oil released in the ocean travels and how it weathers. The relative environmental risks of oil and gas development in the Atlantic and Gulf of Alaska outer continental shelves have been analyzed by the Council on Environmental Quality in its report to the President, on April 18, 1974, entitled, OCS Oil and Gas—An Environmental Assessment.

[52] Basic data contained in the National Petroleum Council's U.S. Energy Outlook, Report to NPC's Committee on U.S. Energy Outlook, December 1972, "Polluting Incidents in and around U.S. Waters, Calendar Year 1971," U.S. Coast Guard, Washington, D.C., 1975. Estimates were obtained by James E. Flinn and Robert S. Reimers. March 1974. Development of Predictors of Future Pollution Problems. EPA Report 600/5-74-005.

[54] An estimated 10 percent of outboard motor oil fuel mixture is unburned. Mussels exposed to water containing 50 parts per billion of these hydrocarbons showed gill damage after 24 hours of exposure; 66 percent died although they were removed after one day and placed in fresh water. Fourteen percent of oysters tested died during the test period of 10 days. Clark, R. C., Jr., and J. S. Finley. November 1974. Environmental Science and Technology, Science News 106(21): 331. Since June 1973 Switzerland has outlawed ordinary motor oil in boat engines and requires instead a special oil that is emulsifiable and biodegradable. Communication by Kohn, Henry H. January 4, 1975. Science News 107 (1):3.

[55] Sanders, H. L., J. F. Grassle and G. R. Hampson. 1972. The West Falmouth Oil Spill! Biology (Woods Hole, Mass.: Woods Hole Oceanographic Institute), Technical report No. 72-20.

wetlands are the most biologically productive areas of the estuary and are most sensitive to oil spills.[56]

Estimates of oil persistence indicate that oil probably persists much longer in salt marshes with soft sediments (up to 10 years) than on rocky shores or coarse sediments (a few months). Oil even at low concentrations threatens fish populations; finfish and shellfish are very susceptible if oil enters spawning and nursery areas. The cleanup procedure to hasten the dissipation of visible oil by the use of dispersant and emulsifying chemicals can be more damaging to the shoreline environment than the oil.

In addition to the potential hazards from oil spills, the development of superports to handle imports and of offshore oil and gas leases whether on the outer continental shelves or in the shallow inshore coastal zone (in Louisiana over 25,000 wells are operated in this productive fishery area) require construction of major pipelines over coastal marshlands. In Louisiana, coastal marshlands and estuaries extend 20 to 40 miles inland from the Gulf of Mexico. Physical and ecological effects in these unstable marshlands include erosion, release of toxic substances from dredge spoils, turbidity, salinity, and other ecosystem changes such as barriers to nutrient flushing, to migration of estuarine organisms and to tidal flow patterns that affect aquatic life. Canal erosion and pipelaying and marsh buggy operations can destroy substantial areas of coastal marsh.[57]

UPSTREAM ACTIVITIES AFFECTING FRESHWATER INFLOWS

Trace element and toxic chemical contaminants from production processes, municipal wastewater treatment, and diffuse sources have been identified as a major problem for the retention of productive fishery habitat in urbanized estuaries. Another projected problem of national importance is the potential hazard from greater leakages of petroleum into the estuarine environment with the development of offshore oil and increased imports. A third broad category of activity which will impinge on the estuarine fishery habitat might be termed "upstream activities"—those removed from the seacoast but which importantly influence the quantity and quality of fresh water entering the estuary.

Construction of dams, diversions of river flow within a basin and from one drainage area to another, control of floods, changes in land use such as increased irrigation, and clearing and channelization of forest and bottom land have in many instances direct and significant effects on estuarine aquatic habitat.

Modification of freshwater flows by dam construction, diversion, and consumption affects the extent of saltwater intrusion, the degree of mixing of fresh and saltwater and the plankton and fish populations.[58] Reduction in freshwater flow increases salinity in former brackish water areas and can reduce the production of shrimp, oysters and other marine life.

In the Sacramento-San Joaquin estuary the changes that can be expected with modification of normal flow patterns typify the effects that can be expected in many estuaries. Losses of fish eggs and young have to be minimized when water is diverted from the estuary; moderate net flow rates have to be maintained to give positive downstream flows. Maintenance of adequate freshwater flows from the Delta into San Francisco Bay are required to maintain "suitable salinities for striped bass spawning and for *Neomysis* . . . for good survival of young striped bass . . . for salmon migrations . . . for sufficient turbidity . . . and for flushing pollutants from diffuse sources out of the estuary."[59] All these requirements should be accounted for in plans for upstream and delta water developments that would modify flows. Already outflow from the Delta is "only about half the natural level due to the combined effect of upstream depletion storage and pumped exports."[60]

Increased population, industrial and municipal usage, and the development of irrigated agriculture, especially in river basins draining arid regions, will continue to increase demand for storage and diversion. The Texas Master Plan proposes to divert most of the flow of the Sabine, Neches Nueces, Trinity, Brazos and Colorado rivers for irrigation use, while an even more ambitious scheme has been discussed—the diversion of water from the mouth of the Mississippi to the Texas High Plains.

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[56] For effects of oil on estuarine communities see Smith, Nelson. March 21, 1972. Effects of the Oil Industry on Shore Life in Estuaries. Proceedings of the Royal Society of London, Series B. 180 (1061):287-296. Also, IDOE. 1972. Baseline Studies of Pollutants in the Marine Environment and Research Recommendations. New York: IDOE Baseline Conference, May 24, 1972.

[57] McGinnis, J. T. et al. December 1972. Environmental Aspects of Gas Pipeline Operations in the Louisiana Coastal Marshes. Report to Offshore Pipeline Committee by Battelle's Columbus Laboratories. St. Amant, L. S. 1971. Impacts of Oil on the Gulf Coast. Trans. 36th American Wildlife and Natural Resources Conference: 206-219; St. Amant, 1971. The Petroleum Industry as it Affects Marine and Estuarine Ecology. Trans. Society of Petroleum Engineers Meeting.

[58] Pritchard, D. W. 1955. Estuarine Circulation Patterns. Proceedings, American Society of Civil Engineers 81:1-11; Ketchum, B. H. 1951. The Flushing of Tidal Estuaries Sewage. Sewage and Industrial Wastes 23(2): 198-209; Ketchum, B. H. Relation Between Circulation and Planktonic Population in Estuaries. Ecology 35: 191-200.

[59] California Department of Fish and Game. April 1973. Maintenance of Fish and Wildlife in the Sacramento-San Joaquin Estuary in Relation to Water Development.

[60] California Department of Fish and Game. June 1972. Ecological Studies of the Sacramento-San Joaquin Estuary: A Decennial Report, 1961-1971: 18.

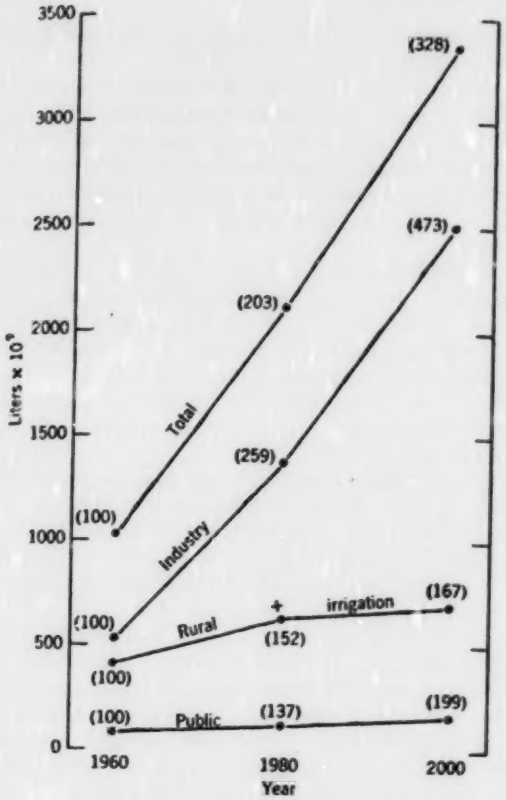

FIGURE 8.—Estimated future water withdrawal in the United States. The figures in parentheses give percentage increase over 1960 values. Source: Data of Murry, C. R. 1968. U.S. Geological Survey Circular 556; Piper, A. M. 1965. U.S. Geological Survey Water-Supply Paper 1797.

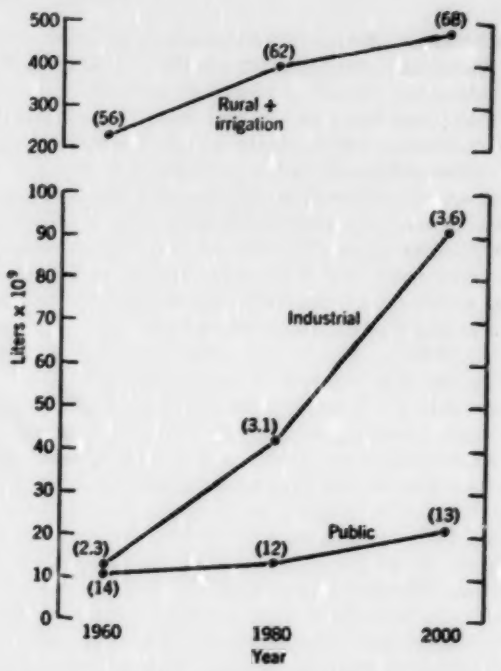

FIGURE 9.—Estimated future water consumption in the United States. Figures in parentheses give percentage of estimated withdrawal. Source: Data of Murry, C. R. 1968. U.S. Geological Survey, Circular 556; Piper, A. M. 1965. U.S. Geological Survey Water-Supply Paper 1797.

Projected future water withdrawals and consumption represent substantial increases over present-day totals (see Figures 8 and 9). Total water withdrawal in the year 2000 is estimated to amount to about 900 billion gallons per day, which compares to a runoff of 1,400 billion gallons daily. Assuming that consumption is 20 percent of total withdrawal, we will actually be losing to the atmosphere 180 billion gallons daily, a small fraction of the runoff. Recycling procedures can be developed to reduce even further the percentage of runoff required to be withdrawn. Consequently, there would appear to be enough fresh water to meet future demands. The pertinent question, however, is whether there is sufficient fresh water in different drainage areas to meet the respective demands and to maintain productive fishery habitats in downstream areas. As population pressures increase and urban activities grow in both the hinterland and coastal zone, the problems of water quality and quantity at the interface between rivers and the estuarine zone can be expected to be exacerbated.

MANAGEMENT IMPLICATIONS

Land and water use in the coastal zone is interrelated with that in the hinterland, both in actuality and policy. The state land use plans should therefore incorporate plans for managing the lands along the coast in such a way as to preserve the ecological values of estuaries, other coastal waters, and marshlands to the maximum practicable degree consistent with essential uses for navigation, recreation, seafood production, power plant cooling, and other uses.

The Coastal Zone Management Act of 1972 administered by the National Oceanic and Atmospheric Administration in its first year of operation has provided assistance to all but one of 34 coastal states and territories wishing to establish resource management plans in defined coastal areas.

The management plans of the coastal zone (including estuaries) should incorporate the flexibility

to be compatible with comprehensive land use planning measures as set out in the new administration bill drafted by the Secretary of the Interior.

Comprehensive plans for the use of the water and land resources of the coastal zone should be based on a careful classification of the coastal zone with respect to uses and the degree of necessary public controls over these uses. Provision should be made for public acquisition of lands and interests in lands required to preserve ecological values and provide other public benefits.

Land and water practices and programs upstream in the drainage area of an estuary importantly influence the quantity and quality of fresh water flowing into estuarine areas. Water management in the estuaries and coastal zone must be integrated with management of upstream water resources to achieve comprehensive drainage basin management. The planning of future developments and diversions upstream must recognize this crucial interrelationship and provide facilities for mitigating losses and preserving values in the estuaries and coastal zones.

Present Federal, state and local processes for making land use and development decisions as they apply to the total estuarine system, including freshwater inflows, should be made adequate to the task. Local governments cannot and should not be bypassed. On the contrary, under an effective state organization with strong regional bodies, local governments should perform an indispensable role in coastal zone management.[1]

There is urgent need to improve environmental impact statements required by Section 102(c) of the National Environmental Policy Act of 1970 (NEPA) for all the changes and activities affecting estuarine areas. Improvement of impact assessment procedures and analyses is required at all levels of federal, state and local governments. This will require a major commitment of resources to attain levels of competency and ensure that the evaluations are thorough.

An early improvement in making the content of environmental impact evaluation more relevant could be brought about by re-establishing a coordination arrangement between the Water Resources Council and the Interagency Committee on Marine Resources of the Federal Council for Science and Technology, which is now responsible for the policy coordination aspect of the National Marine Sciences Program. This would assure that research programs are designed to furnish the information for proper integration of water resources planning and estuarine and coastal zone management.

Estuarine research programs of Federal and state agencies should be strengthened to provide a better basis for the establishment of water quality standards for estuarine and coastal waters.

While programs of research have been initiated on problems related to estuarine and coastal zone management, they need to be accelerated and broadened to provide information so that effective means can be taken to monitor and predict the impact of upstream development and waste disposal on coastal zone waters and the oceans. Additional knowledge is needed to protect, enhance, and develop the coastal zone environment, particularly estuaries.

High priority should be given and the necessary support found for research on the determination of water quality requirements for various water uses and for the criteria which serve as the basis for water quality standards.

Additional investigations are needed to determine the effects of waste disposal in estuarine waters and to determine the extent of pollution so that measures to cope with problems can be devised. These programs might be merged with and supplement the ongoing and emerging programs of research now under the auspices of the National Oceanic and Atmospheric Administration—Marine Ecosystem Analysis (MES) and Marine Monitoring Assessing and Prediction (MARMAP).

[1] The principles drawn up by the California Advisory Commission on Marine and Coastal Resources propose a structure and function for coastal zone management organization which includes state, regional and local contributions as essential components. These principles are stated in Appendix B.

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APPENDIX A
TABLES

Appendix Table 1.—A summary of legislation relating to coastal and estuarine zones

Zone	Comprehensive coastal zone planning legislation	Wetlands	Industries and power plant siting	Shoreline—recreation
Alabama	None at present—in the planning stage.	U.S. Army Corps of Engineers projects deemed harmful are refused.	Alabama Water Improvement Commission regulates the location of industries and domestic pollution sources.	
Alaska	None at present—in the study stage.			
California	Coastal Zone Conservation Act (1972)—to develop plans and control development. Permits required for any development in the coastal zone. The California Comprehensive Ocean Area Plan was completed in 1972.		A power plant siting bill was passed in 1974.	
Connecticut	$3.5 million study of Long Island Sound to develop a comprehensive plan for this area.	Wetlands Protection Act—1969 —Inventory of all wetlands. —No dredging or construction on designated wetlands without a permit.		
Delaware	Delaware Coastal Zone Act (1971)—to control the location, type, and extent of industrial development in coastal areas, prohibition of new heavy industries.	Delaware Wetlands Act (1973)—permits required for virtually all activity in the wetlands.	The state has banned heavy industry within two miles of the coast, with permits required for other uses.	An assessment of present and future demands on coastal zone.
Florida	Environmental Land and Water Management Act (1972): land development regulations for "area of critical state concern."			Land Conservation Act (1972)—to finance the cost of recreation lands.
Georgia		Coastal Marshlands Protection Act (1970): "No person may remove, fill, dredge, drain, or otherwise alter any marshlands within the estuarine areas without first obtaining a permit . . . ."		
Hawaii	Legislation requiring a coastal plan passed in 1973.			Shoreline Setback Areas (1971). Construction within 20 to 40 feet from edge of vegetation growth is prohibited without a special permit.
Louisiana	No coastal zone plan.			
Maine	"Coastal Development Plan" being prepared.	Wetlands Preservation Act (1967)—State Wetlands Control Board can impose any conditions regarding dredging, filling, etc., on coast if they feel it is in public's interest.	Legislation to halt heavy industry on coast is now pending.	
Maryland	Still being developed. A critical areas bill (S.B. 500) was enacted.	Wetlands Act (1970; amendment) no dredging or filling without a permit		Shore Erosion Control Act (1970 as amended)—provides loans for shore erosion protection devices.

Zone	Comprehensive coastal zone planning legislation	Wetlands	Industries and power plant siting	Shoreline—recreation
Massachusetts	A commission has been created to develop a comprehensive plan for estuarine area management.		Power plant siting law was recently enacted.	
Mississippi	Coastal zone management plan in review stage.	Coastal Wetlands Protection Act (1973)—designates the Marine Resources Council as the regulatory agency for activities on wetlands.		
New Hampshire	No plan at present.	Wetlands Act (1967)—controls dredging and filling of tidal areas. Dredge and Fill Act (1971) promulgates rules and regulations for dredging in tidal areas.	Power Plant Siting (1971)—sites must be approved by PUC and not environmentally detrimental.	
New Jersey	Plan being formulated. Some coastal zone land uses regulated by 1973 law.	Wetlands Act (1970) permit required for any dredging, filling, polluting, building, or otherwise altering wetlands—wetlands being mapped.		
New York	Plan being formulated. Coastal zone authority influences land use.	New York Wetlands Act (1971)—moratorium on wetland alterations.	Power plant siting law.	Multi-year study begun in 1971 inventorying Long Island Sound resources.
North Carolina	Coastal Areas Management Act (1974)—also a preliminary, comprehensive plan prepared December 1972. Land Policy Act (1974).	Wetlands Protection Act (1971)—authorizes the adoption of rules to protect marshes and contiguous lands. Dredge and Fill Act (1971)—makes permits required.		
Oregon	Coastal Zone Management Plan Act (1971) provides for a comprehensive plan to be submitted to State Legislature by 1975.		State has a power plant siting law.	Oregon Land Use Law (1973) regulating land uses. Beach Access Act (1967)—citizen's right to unrestricted beach use up to vegetation line.
Puerto Rico			As required under Federal Water Pollution Control Act, no new municipal or industrial discharges without special authorization.	
Rhode Island	Comprehensive plan being developed. Some coastal zone activities regulated by state permit system.	Coastal Wetlands Act (1965), land use restrictions in such areas. Intertidal Salt Marsh Act (1965)—permits needed to fill, dredge, etc.		Coastal Management Council Act (1971) to administer management program for coastal areas.
South Carolina	No plan at present.			No major legislation but increased study and survey of coastal areas.
Texas	Coastal Public Lands Management Act (1976) provides for the comprehensive management of state-owned coastal lands, and establishes permit system for construction on coastal islands and submerged lands. The Texas Council on Marine Related Affairs was created in 1971, to study and plan for marine resources.			Public ownership of state beaches up to vegetation line.
Virginia	Plan being developed.	Wetlands Act (1972)—a permit system for wetlands regulation.		A coastal zone management program is being undertaken.
Washington	Shoreline Management Act (1971)—sets responsibilities of state and local areas for permit system, and inventories.	Marshes, bogs, swamps, floodways, and river deltas are regulated under the Shoreline Management Act.	Thermal Power Plant Siting Act (1970)—environmental and biological considerations will be main guidelines in location of sites.	

Appendix Table 2.—Major U.S. waterways

10 longest rivers (miles)	10 rivers with highest flows (cubic feet per second)	Waters of 10 largest urban areas
Missouri (2,564)	Mississippi (620,000)[1,3]	Hudson River—New York Harbor
Mississippi (2,348)	Ohio (255,000)[1]	Los Angeles Harbor
Rio Grande (1,885)	Columbia (235,000)[2]	Lake Michigan and other waters of Chicago area
Yukon (1,875)	Missouri (70,000)[2]	Delaware River (Philadelphia)
Arkansas (1,450)	Tennessee (63,700)	Detroit River and Detroit area tributaries
Colorado (1,450)	Alabama-Coosa (59,000)	San Francisco Bay and Sacramento River
Columbia—Snake (1,324)	Red (57,300)[1,3]	Potomac River (Washington, D. C.)
Ohio (1,306)	Arkansas (45,200)[2]	Boston Harbor
Red (1,222)	Susquehanna (35,800)	Ohio River (Pittsburgh)[2]
Brazos (1,210)	Willamette (30,700)	Mississippi and Missouri Rivers (St. Louis)[2]

[1] Contained in first (or second) columns.
[2] Includes Atchafalaya River (about 25 percent of flow).
[3] Includes flow of Ouachita River.
Source: Environmental Protection Agency. 1974. National Water Quality Inventory: Report to Congress. Table I-1.

Appendix Table 3.—Major waterways: Water quality trends 1963-72[1].

Parameter	Number of reaches analyzed	Percent of reaches improved[2]
Suspended solids	28	82
Turbidity	29	79
Fecal coliforms (membrane filter)	9	78
Ammonia	25	76
BOD_5	31	74
Total coliforms (membrane filter delayed)	23	70
COD	20	70
Temperature	33	67
Total coliforms (most probable number)	9	67
Dissolved solids (105° C)	28	64
Chlorides	34	62
Dissolved oxygen	31	61[3]
Dissolved solids (180° C)	23	61
Odor	5	60
pH	34	59[4]
Total coliforms (membrane filter immediate)	12	58
Phenols	12	58
Dissolved phosphate	18	56
Sulfates	33	55
Organic nitrogen	11	55
Total phosphate	16	44
Alkalinity	32	41[3]
Nitrite	5	40
Nitrite plus nitrate	27	37
Color	30	33
Nitrate (as NO_3)	19	26
Nitrate (as N)	17	24
Total phosphorus	28	18

[1] Based on median values at each reach. Reaches included only if they contain one or more stations with at least seven samples each. Parameters included only if five or more reaches were measured.
[2] Except where noted, "improved" means that 1968–72 median concentrations are lower than 1963–67 median concentrations at mean station.
[3] "Improved" means higher concentration.
"Improved" means pH becomes higher (less acid).
Source: Council of Environmental Quality, Fifth Annual Report, Table 20, p. 285.

Appendix Table 4.—Major waterways: Reference level violations, 1963 to 1972

Parameter	Reference level and source[1]	Percent of reaches exceeding reference levels		
		1963–67	1968–72	Change
Suspended solids	80 mg/l-aquatic life	26	14	−12
Turbidity	50 JTU-aquatic life	28	28	0
Temperature	90° F-aquatic life	0	0	0
Color	75 platinum-cobalt units-water supply	0	0	0
Ammonia	0.89 mg/l-aquatic life	16	6	−10
Nitrate (as N)	0.9 mg/l-nutrient	12	24	+12
Nitrite plus nitrate	0.9 mg/l-nutrient	18	26	+8
Total phosphorus	0.1 mg/l-nutrient	34	57	+23
Total phosphate	0.3 mg/l-nutrient	30	41	+11
Dissolved phosphate	0.3 mg/l-nutrient	11	22	+11
Dissolved solids (105° C)	500 mg/l-water supply	25	18	−7
Dissolved solids (180° C)	500 mg/l-water supply	28	12	−16
Chlorides	250 mg/l-water supply	12	9	−3
Sulfates	250 mg/l-water supply	12	12	0
pH	6.0–9.0-aquatic life	0	0	0
Dissolved oxygen	4.0 mg/l-aquatic life	0	0	0
Total coliforms (MFD)[2]	10,000/100 ml-recreation	24	13	−11
Total coliforms (MFI)[2]	10,000/100 ml-recreation	50	30	−20
Total coliforms (MPN)[2]	10,000/100 ml-recreation	23	20	−3
Fecal coliforms (MPN)[2]	2,000/100 ml-recreation	45	21	−24
Fecal coliforms (MPN)[2]	2,000/100 ml-recreation	17	43	+26
Phenols	0.001 mg/l-water supply	86	71	−15

[1] With the exceptions that follow, reference level designations are from "Guidelines for Developing or Revising Water Quality Standards," EPA Water Planning Division, April 1973; for ammonia, chlorides, sulfates, and phenols, "Criteria for Water Quality," EPA, 1973 (Section 304(a)(1) guidelines); and for nitrate (as N), "Biological Associated Problems in Freshwater Environments," FWPCA, 1966, pp. 132–133.
[2] Membrane filter delayed, membrane filter immediate, most probable number.
Source: Environmental Quality Fifth Annual Report, Council on Environmental Quality.

Appendix Table 5.—Published effluent guidelines for industries as of June 30, 1974

Industry	Proposed	Final (effective date)
Fiberglass	8/22/73	1/22/74
Beet sugar	8/22/73	1/31/74
Cement	7/7/73	1/20/74
Feedlots	9/7/73	2/14/74
Phosphates	9/7/73	2/20/74
Flat glass	10/17/73	2/14/74
Rubber	10/11/73	2/21/74
Ferroalloys	10/18/73	2/22/74
Electroplating	10/5/73	3/8/74
Asbestos	10/30/73	2/26/74
Inorganics	10/11/73	3/12/74
Meats	10/29/73	2/28/74
Plastics and synthetics	10/11/73	4/5/74
Nonferrous metals	11/30/73	4/8/74
Cane sugar	12/7/73	3/20/74
Fruit and vegetables	11/9/73	3/21/74
Grain mills	12/4/73	3/20/74
Soaps and detergents	12/26/73	2/12/74
Fertilizer	4/8/74	7/2/74
Petroleum	12/14/73	5/9/74
Dairy	12/20/73	5/28/74
Leather	12/7/73	4/9/74
Pulp and paper	1/15/74	5/29/74
Organics	12/17/73	4/25/74
Builders paper	1/14/74	5/9/74
Seafood	2/6/74	6/25/74
Timber	1/3/74	4/18/74
Iron and steel	2/19/74	6/28/74
Textiles	2/5/74	7/5/74
Steam and electric power	3/4/74	Not yet published

Source: Environmental Quality. The Fifth Annual Report of the Council on Environmental Quality, 1974. Table 8, page 141.

APPENDIX B

Principles for Coastal Zone Management

Drawn up by

California Advisory Commission on Marine and Coastal Resources

1. Findings and Declarations

a. Legislative findings should be brief and directed toward the positive aspects of the regulatory scheme.

2. State Coastal Zone Management

a. The state should provide leadership in assisting local governments in the planning and management of the coastal zone.

b. Coastal zone management legislation should designate a single state organization to provide leadership in the planning and management of the coastal zone.

c. The state organization to be selected to administer the plan of regulation should be directed by a board consisting of persons qualified and experienced in the development, conservation or use of marine and coastal resources (e.g., concerned with environmental quality, conservation and recreation, living marine resources, land use planning and coastal development, and economics and law of natural resources) and persons not required to have specialized knowledge.

d. The state organization should be required to establish continuing liaison and coordinate its activities with all other major state and private agencies directly interested in the administration of the coastal zone.

e. The state organization should be empowered to require periodic review and updating of all local and regional plans.

f. The state organization should be designated as the state coastal zone authority for all purposes stated in any federal coastal zone management legislation and be given the authority to administer any statewide program of research and planning pertaining thereto.

g. The state organization should be a clearinghouse for planning information pertaining to the development and conservation of the marine and coastal resources of the state.

h. The technical advisory committee should consist of the California Advisory Commission on Marine and Coastal Resources ("CMC").

i. The advisory committee should be given the responsibility to advise the state organization either when requested by it or when deemed appropriate by the committee.

2. Regional Coastal Zone Management

a. Coordination of this planning and management function will require regional entities, encompassing aggregations of several local governments.

b. Regional boards should be designated to supervise the implementation of the program.

c. Regional areas should be designated following county lines and be functionally related to resource planning.

d. The governing boards for the designated areas should consist of persons qualified and experienced in the development, conservation or use of marine and coastal resources (e.g., concerned with municipal government, county government, water use, environmental quality, recreation and conservation, land use and land use planning, living marine resources, and economics and law of natural resources).

4. Local Government Coastal Zone Management

a. The planning and management of the coastal zone is primarily the responsibility of local government.

b. Planning and management of the coastal zone located within the boundaries of units of local government are and should remain primarily the responsibility of units of local government in accordance with state criteria.

c. Local governments should coordinate their planning and management within overall state policy and should administer the coastal zone under the state's certification.

5. Permit Area Boundary

a. The state organization selected should have legally precise and ascertainable boundaries.

b. Any administrative discretion to expand the coastal zone should be of short duration.

c. The practicability of the plan of regulation should be considered in determining the extent of the defined coastal zone, it being more desirable to have a coastal zone with numerous exceptions based upon unquantified considerations.

6. Coastal Zone Policy and Criteria

a. The state organization selected should formulate and adopt state policy for coastal resources conservation and development.

b. Criteria for certification of local plans and programs should be established and administered by the state.

c. To the extent practicable, principles underlying criteria to be applied by any new state coastal zone management should be established prior to or concurrently with the implementation of the regulatory aspects of that system.

d. The criteria to be developed should include components for all lawful uses of the coastal zone and none should be generically prohibited.

e. The criteria to be developed should facilitate an optimum combination of all lawful uses in the coastal zone by a consideration of all private and public benefits and costs resulting from them.

f. Special consideration in forming criteria should be given to uses which cause irreversibility in potentially permanent flow (e.g., renewable) resources.

g. The staff of the state organization selected should be given the responsibility of preparing recommended planning criteria.

h. A technical advisory committee should have the responsibility to review and comment upon recommended planning criteria.

7. COASTAL ZONE PLAN DEVELOPMENT

a. The state organization selected should ultimately incorporate the Comprehensive Ocean Area Plan ("COAP") into the state plan.

b. The state organization selected should integrate regional plans developed by the regional boards into the state program.

c. Regional boards should be required to prepare regional plans incorporating coastal elements developed by units of local government to the extent that the same are consistent with the criteria developed by the state organization.

d. Regional planning entities should provide a comprehensive format for coordinated planning and management in accordance with state policy objectives.

e. Primary responsibility for management of marine living resources should not be affected by coastal zone management legislation.

f. The state organization should certify conformance of regional plans to state policy.

8. LAND USE PERMIT SYSTEM

a. Units of local government should be required to give notice to the regional boards of permits granted for regulated uses of the coastal zone with supporting data for the decision made, and the regional boards should have the power to review the same within a designated period of time (e.g., 30–60 days) to determine whether the decision meets with the relevant criteria. If a regional board does not give notice of nonconformance with such criteria within such period, the permit shall be effective.

b. Regional boards should have the power to issue orders to units of local government or their permittees to rescind permits issued for uses not conforming to relevant criteria.

c. Regional boards should have the power to obtain injunctions and other appropriate legal relief.

d. Where the matter is of regional concern, regional boards should also have the power to hear appeals from denials of permits by units of local government and to confirm or rescind such action.

e. The state organization should upon petition of an aggrieved person, public agency, unit of local government or its own motion review any action or failure to act by a regional board with respect to any requested use of the coastal zone considered not in accordance with state criteria.

f. State agencies should be required to give notice to the appropriate regional board of regulated uses of the coastal zone proposed to be made by them and of permits proposed to be granted for such uses with supporting data for the decision made with respect thereto. The appropriate regional board should have the power to review the decision within the designated period of time (30–60 days) to determine whether the same meets with the relevant criteria of the regional plan. If the appropriate regional board does not give notice of nonconformance with such criteria within such period, the proposed use shall be deemed approved.

9. ECONOMICS AND FINANCING

a. The legislation should provide funding for all affected governmental agencies at all levels to enable them to perform assigned responsibilities in an adequate and timely fashion.

b. The state organization should be structured so as to take maximum advantage of existing organization, personnel and equipment.

c. The state organization selected should allocate to the regional boards from funds appropriated to it such monies as may be necessary for their professional staffing and other administrative expenses.

d. The legislation should recognize private property rights in the coastal zone and require payment of fair compensation in the event that any taking is effected thereunder.

e. The legislation should give appropriate recognition to the effect of the plan of regulation of units of local government and should provide a means for equalizing benefits as well as costs incurred in environmental maintenance or sustaining low density uses.

THE EXTRACTIVE INDUSTRIES IN THE COASTAL ZONE OF THE CONTINENTAL UNITED STATES

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ABSTRACT

The extractive industries in the coastal zone consider all known mineral sources excluding petroleum, that presently occur or may occur in the future within the estuaries, the nearshore continental shelf waters, and the adjacent land areas within continental United States exclusive of the Great Lakes. This includes all activities in the recovery of natural materials from the sediments and rocks of the earth's crust and from the water column and the preparation and treatment of these natural materials in order to make them suitable for use.

Mineral extraction, excluding petroleum, is presently nonexistent in most estuaries and very limited both in commodities and quantities in the few estuaries where extraction is taking place. Any consideration of estuarine and offshore mining must deal with the potential. To develop an adequate inventory of the resource potential of the United States coastal areas will necessitate a massive and coordinated detailed study of the surface and subsurface geology. Most extractive industries, whether in, adjacent to, or distantly remote from an estuarine system will have some impact upon the pollution of the coastal zone; however, no two extractive industries will have similar effects or degrees of pollution impact upon the estuarine system.

A basic knowledge of the mineral reserves and the general economic value to man is essential prior to the development of any land and water use management plans involving the continued development of our coastal zone. Economics of a given mineral resource may change dramatically in response to new technological advances, discoveries of new ore deposits, or as industrial and social demands change through time. Such changes can have drastic effects upon the same management programs which define land and water uses. The resulting dilemma becomes of paramount importance: the need to protect a delicately balanced estuarine system, upon which man is dependent, and at the same time dramatically increase its use and modification for materials which man is also dependent upon.

INTRODUCTION

This report on the extractive industries in the coastal zone considers all known mineral resources excluding petroleum, that presently occur or may occur in the future within the estuaries, the nearshore continental shelf waters, and the adjacent land areas within continental United States exclusive of the Great Lakes. Also, it does not directly consider the consequences of dredging, particularly as related to channel and harbor dredging and maintenance.

The estuarine zone or coastal zone, as used in this report, refers to the geographic region including the coastal counties between the landward limit of tidal influence and the three-mile limit to seaward ("National Estuarine Pollution Study," 1970, p. 5).

> The estuarine zone is an ecosystem. That is, it is an environment of land, water, and air inhabited by plants and animals that have specific relationships to each other. This particular ecosystem is the interface between land and ocean, and one of its key components is human society (p. 5).

In order to evaluate the mineral resource potential of the coastal zone, one must first establish what the mineral resources are. Any naturally occurring material, whether it be an individual mineral, an aggregate of minerals combined into unconsolidated sediments or consolidated rocks, or a natural material in the form of liquid or gas is a mineral resource if its physical or chemical characteristics make it a desirable ingredient in man's technological society. Since almost all natural materials may be usable resources in some form and at some time or other, whether it be for general land fill, beach replenishment, construction materials, or as a source of some metal or fuel, all of the materials bounding and occurring within the coastal zone become potential resources.

The extractive industries include all forms of recovery of natural materials from the sediments and rocks of the earth's crust and from the water column comprising the oceans and estuaries. More specifically these include (1) breaking of the surface soil in order to extract natural materials; (2) all activities or processes involved in the extraction of natural

materials from their original location; and (3) any preparation and treatment of these natural materials in order to make them suitable for use. This broad array of activities associated with the mineral extraction industries range from the exploration and mining activities, to the processing and treatment plants, to the complex transportation systems involving pipelines, channels and harbors. The potential conflict with other coastal uses and the potential impact of these activities upon the delicate balances of the fragile and limited estuarine zone have given birth to a dilemma that is slowly growing to prohibitive proportions.

Various geologists have projected that the major mineral reserves in the United States, which are presently derived from land, will be exhausted by the year 2000 (Moore, 1972). If this is the case, then where are the future resources to come from?—the coastal areas and the continental shelves! Since the shelves are geologically nothing more than submerged portions of the continent, McKelvey (1968) believes that it is logical to assume that the mineral potential should be roughly comparable to that which has already been found on land. Partly for these reasons, Moore (1972) projects a truly large-scale undersea mining industry by 1980 with complete dependence upon this source by the year 2000. The fact that the United States Department of the Interior has recently issued a "Draft Environmental Impact Statement" in connection with undersea mining, as well as a set of proposed regulations for the actual leasing and mining of undersea hard rock minerals, underscores the anticipation of the increased development of these presently poorly known resources.

However, the total present world production of minerals from the sediments and rocks comprising the sea floor of the continental margins, excluding oil and gas, is only about $470 million annually or 2 percent of the on-land production of these minerals. Another $415 million worth of minerals are presently extracted from seawater making the present value of all extractive resources from the marine environment a minor part of the total mineral production (Rigg, 1975). However, to date only a very small percentage of the coastal and shelf environments have even been explored for anything other than possibly petroleum. If the major thrust for future mineral resources is on the continental shelf, then the coastal zone will play an ever increasing role in the extractive industries. This role will include some mining itself, but probably of greater significance will be the critical role the estuaries will play in supporting the massive transportation system and processing plants necessary for the offshore extractive industries.

At the present time, it is nearly impossible to describe accurately or completely the location and size of existing extractive industries in the coastal zone, to say nothing about the mineral reserves. In fact, the mineral resource potential of the estuaries and continental shelves, with few exceptions are at best only superficially known. The reasons for this are: (1) the geologic and mining agencies that monitor these industries do not differentiate the extractive operations that are related to the coastal zone from any other region; (2) for competitive reasons, the same agencies generally are not able to relate production statistics and rarely do they have access to good reserve information if it is even known; and (3) detailed geologic investigation, exploration, and research in the coastal zone is extremely expensive, technologically difficult, and generally a relatively "new" science.

Recent inquiries by the author, to the geological surveys of the coastal states, underscored both the lack of knowledge of the resources and the meager effort to monitor any existing mineral extraction within or adjacent to the estuaries or the offshore areas. In fact, much of the existing published data, such as Table IV.2.8 entitled "Major Exploitation of Coastal Mineral Resources" in the "National Estuarine Pollution Study" (p. 124, 1970), is extremely misleading. The table states that in 1967 there were 1,479 coastal operations in the United States exploiting $373,192,000 worth of minerals including 168 metal operations, but excluding all petroleum and other mineral fuels. These numbers are only correct if one includes all of the inland coastal plain areas. A study of the case histories of specific estuarine zones within the same publication, as well as in "The Economic and Social Importance of Estuaries" (Environmental Protection Agency, 1971) and the "National Estuarine Pollution Study" (United States Department of the Interior, 1970) suggest that mineral extraction is actually nonexistent in most estuaries and very limited both in commodities and quantities in the few estuaries where extraction is taking place. To adequately know and inventory the resource potential of the United States coastal areas will necessitate a massive and coordinated detailed study of the surface and subsurface geology—a mammoth undertaking. Only slow, isolated, and individual progress is presently being made in this direction.

Consideration of estuarine and offshore mining must deal with the potential since the present mineral production from below the sea is limited to only a few commodities, the major one being petroleum. However, the present economic and technological restraints, which are the major limiting factors of mining the sea floor, are rapidly being overcome by

the current efforts within the rapidly changing offshore petroleum exploration and development. These include: (a) a rapid annual increase in the number of holes drilled; (b) an expansion into deeper waters further from shore; (c) a complementary increase in the size and capabilities of the offshore drilling rigs; and (d) an increasing sophistication of underwater operating facilities and pipeline systems. As the petroleum industry continues to expand its exploration and operations into the coastal and offshore areas, there will be an increase in the discovery and recovery of associated minerals that can be recovered by pumping and solution mining. Such minerals as sulfur and potash occur in salt domes, which are major petroleum reservoirs. The sophisticated technology necessary for the exploration and mining of other types of mineral deposits from the sea floor will quickly follow.

The United States' economy needs over 4 billion tons of raw mineral supplies to produce $1.75 billion worth of domestically produced energy and processed materials of mineral origin annually; the demand still far exceeds the domestic production of both raw materials and processed minerals (Morgan, 1974). The Secretary of the Interior issued in mid-1973 his "Second Annual Report Under the Mining and Minerals Policy Act of 1970," in which he stated that the "development of domestic mineral resources is not keeping pace with domestic demand," for nine major reasons (Morgan, 1974):

> 1. Mineral imports have an unfavorable impact upon the United States' balance of trade and upon the United States' balance of payments;
>
> 2. Expropriations, confiscations, and forced modifications of agreements have severely modified the flow to the United States of some foreign mineral materials produced by United States firms operating abroad, and have made other materials more costly;
>
> 3. United States industry is encountering greater competition from foreign nations and supranational groups in developing new foreign mineral supplies and in assuring the long-term flow of minerals to the United States;
>
> 4. Development of the United States transportation net is not keeping pace with demand, thus seriously affecting the energy and minerals industries;
>
> 5. Removal of billions of tons of minerals annually from the earth contributes to a variety of disturbances;
>
> 6. The United States mining, minerals, metal, and mineral reclamation industries are encountering increasing difficulty in financing needed expansion of capacity and the introduction of new improved technology;
>
> 7. Management of the resources of the public lands, including the continental shelves, must be improved;
>
> 8. The factual basis for the formulation and implementation of environmental regulations must be improved, so that man and nature are properly protected with minimum dislocation of important economic activities; and
>
> 9. The United States Government information base for the conduct of its mineral responsibilities is grossly inadequate.

Morgan also points out that the world economy has grown faster recently than the United States' economy has; this has resulted in increased competition for needed raw materials. Likewise, it is becoming increasingly difficult to sell manufactured articles in world markets to pay for imported raw materials. Thus, the United States is faced with an ever-increasing need for self sufficiency in mineral resources.

Most extractive industries, whether in, adjacent to, or distantly remote from an estuarine system will have some impact upon the pollution of the coastal zone. Since most of the drainage systems from the land ultimately end in the estuaries, the drainage network funnels a great variety of contaminants into the coastal system. These contaminants are derived from a multitude of sources including the extractive industries, agriculture, urban, and industrial wastes. Consequently, coal becomes part of the sediment load entering the Potomac River, dissolved phosphorus enriches the waters of the Pamlico River in North Carolina, and dissolved metals reach San Francisco Bay from the mines in the Sierras.

On the other hand, no two extractive industries will have similar effects or degrees of impact. For example, a sand and gravel quarry adjacent to an estuary can be completely sealed so that no sediment reaches the estuarine waters, while a mercury mine many miles from the estuarine zone may contribute minute but lethal concentrations of dissolved mercury to the bottom muds. Unless the extractive industry is directly within the estuary, the processing plants and allied industries utilizing the recovered commodity will often have a greater potential or actual long-term pollution effect upon the estuarine system than the mechanical or the chemical extraction in an adjacent land or offshore area will have.

The economic value and demand for a given commodity is determined by (a) the specific qualities of that material which in turn determines the technological uses; (b) the availability and concentration of the material; (c) by the cost of recovering and processing the commodity; (d) transportation of the ore for processing as well as the distance to markets; and (e) time delays resulting from possible restraining orders, hearings, and court litigations. Knowledge of these parameters is essential prior to the development of any land and water use management plans involving the continued development of our coastal zone. However, the economics of a given mineral resource may change dramatically in response to new technological advances, discoveries of new ore deposits, or as industrial and social de-

mands change through time. Such changes can have drastic effects upon the same management programs which define land and water uses.

As we begin to go to the sea for more of our mineral resources to offset dwindling onshore supplies, spiraling prices, and satisfy the increasing need for national independence, new pressures will develop. These new pressures, when combined with the existing pressures of growing technology and population, can only have significant increased pollution impact upon an already environmentally overstressed coastal system. According to the "National Estuarine Pollution Study" (1970, p. 20), the coastal counties of the United States contain 15 percent of the land area; however, they carry 33 percent of the population and 40 percent of all manufacturing plants in the United States—and they continue to grow. Thus, man's dilemma continues to grow—the need to protect a delicately balanced natural system, upon which man is dependent, and at the same time dramatically increase its use for materials on which man also depends.

Before discussing the specific extractive industries in the estuarine zone, the interrelationship of man and mineral resources should be put into proper perspective. This interrelationship is summarized by T.S. Lovering (1969, p. 110):

> Whether a particular type and grade of mineral concentrate at a particular location in the earth's crust is or can become an ore (a deposit that can be worked at a profit), moreover, depends on a variety of economic factors, including mining, transportation, and extractive technology. The total volume of workable mineral deposits is an insignificant fraction of 1% of the earth's crust, and each deposit represents some geological accident in the remote past. Deposits must be mined where they occur—often far from centers of consumption. Each deposit also has its limits; if worked long enough it must sooner or later be exhausted. No second crop will materialize. Rich mineral deposits are a nation's most valuable but ephemeral material possession—its quick assets. Continued extraction of ore, moreover, leads, eventually, to increasing costs as the material mined comes from greater and greater depths or as grade decreases, although improved technology and economics of scale sometimes allow deposits to be worked, temporarily at decreased costs. Yet industry requires increasing tonnage and variety of mineral raw materials; and although many substances now deemed essential have understudies that can play their parts adequately, technology has found no satisfactory substitutes for others.

THE EXTRACTIVE INDUSTRIES AND THEIR POLLUTION IMPACT UPON THE COASTAL ZONE

The extractive industries that occur either within the estuaries, on the nearshore continental shelf, or adjacent land areas can be placed into three general categories: the surface, subsurface, and aqueous deposits (Table 1). Each category of deposit has its own type of materials and problems associated with recovery and consequently, will be considered separately.

Table 1.—Categories of extractive resources and their development potential within the coastal zone

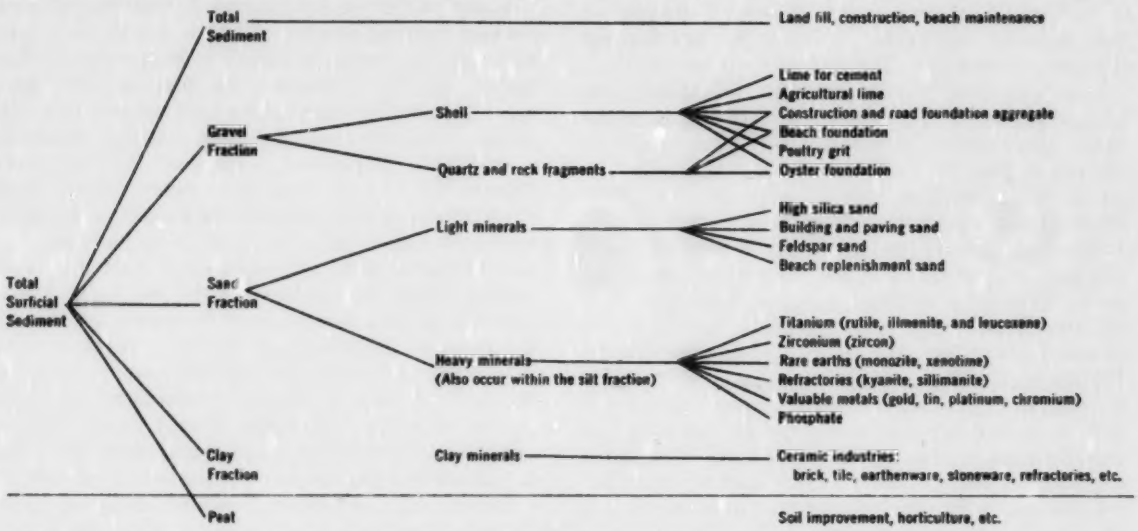
Resource category	Extractive resources	Resource potential		
		Past or current production	Near future	Long range
Surface deposits				
Unconsolidated to partially consolidated sediment	Total sediments	•••	•••	•••
	Shell gravels	••	••	••
	Quartz and rock gravels	•	••	•••
	Light mineral sands	•	•	•
	Heavy mineral sands	••	••	••
	Salt	•	•	•
	Clay minerals	•	•	•
	Phosphate	•	••	•••
	Peat	•	•	•
Consolidated Rock	Rock aggregate	NP	•	••
	Limestone	NP	•	•
Subsurface deposits				
Pumpable materials				
Gas and fluids	Oil	•••	•••	•••
	Natural gas	•••	•••	•••
	LPG	•••	•••	•••
	Geothermal energy		•	••
Soluble solids	Sulfur	••	•••	•••
	Potash	•	••	•••
	Salt	•	••	••
Slurry solids	Phosphate	NP	•••	•••
	Glauconite	NP	•	•
	Sand	NP	•	••
Partially consolidated to consolidated rocks	Phosphate	NP	••	•••
	Fuels (coal, uranium, etc.)	NP	••	•••
	Metals (gold, silver, copper)	NP	••	•••
Aqueous deposits				
	Chlorides	••	•	•
	Magnesium	•••	•••	•••
	Bromine	•••	•	•
	Fresh water	•	•••	•••
	Other materials	NP	•	••

KEY: NP—No known production
•—Minor source or potential
••—Moderate source or potential
•••—Major source or potential

Surface Deposits

The natural materials occurring within or constituting the surficial deposits of the estuarine zone are not only extremely varied in composition, but also in their potential use (Table 2.). In general, the

Table 2.—Utilization of surficial sediment deposits



materials in this category are unconsolidated or poorly consolidated sediment which are capable of being dredged directly without the problems of removing overburden sediments or breaking up consolidated materials. These materials are generally only renewable over extended periods of time. Under local high energy conditions, and if there is an adequate source and supply, some sediment deposits can be rapidly renewed; examples of such deposits are sands and gravels associated with inlets, near shore shoals and capes, and river mouths.

For the most part the deposits considered here are low value commodities (the exceptions being some of the heavy minerals, Table 2.) that require very modest, if any, benefaction or preparation prior to use. Also, because of this low unit value, the commodities have limited and often local markets that are dictated by the very high transportation costs. Consequently, most operations are very small scale, low budget, and temporary depending on the highly variable local markets and economies.

The surface deposits represent the most widely exploited group of mineral resources within the coastal waters today, with the major exception of petroleum. The present and future importance of these surface resources and the resulting pollution potential to our estuarine system, will be considered in more detail. The surficial deposits include the following commodities: sand and gravel, heavy and light minerals, shells, clay, peat, and total sediment for land fill.

SAND AND GRAVEL

The rising demand for sand and gravel is reflected in the total United States consumption which has accelerated from 500 million tons in 1954 to 980 million tons by 1970, with a projection of 1,670 million tons by 1985 and 2,530 million tons annually by 2000 (Grant, 1973). The rate of consumption of sand and gravel during 1970 amounted to 5 tons per capita, which is greater than all other mineral commodities except water (McKelvey, 1968). Most of this sand and gravel comes from the land, even so, sand and gravel probably represent the most important commodities recovered from the coastal zone in terms of both volume and value. However, since no records are kept of production in the estuarine zone, the commonly quoted values are highly suspect. Nevertheless, the explosive urban and industrial growth in the coastal areas, which demand an ever-increasing amount of construction aggregate, is rapidly depleting the known land supplies in nearby areas or is burying them in their urban sprawl. Since most of the cost of these essential low unit-value commodities is in transportation, a proximal location to the market is essential. However, since such large reserves and acreages are necessary, faced with strong urban zoning restrictions, resource development near the markets in metropolitan areas becomes essentially prohibitive. Thus, as transportation costs rise and as land supplies dwindle, the extensive and high quality deposits of submarine sand

and gravel occurring in the coastal zone become increasingly more attractive. England has already been forced to the sea to supply over 13 percent of the required aggregate, utilizing 75 ocean-going dredges representing 32 companies (Hess, 1971).

Manheim (1972) estimated that 400 billion tons of sand grading 75 percent or more are present in the upper three meters covering 20,000 square miles of the continental shelf off the northeast United States coast. Pings and Paist (1970) have estimated that sand deposits cover about 50,000 square miles of the Atlantic shelf and areas about half as large on both the gulf and Pacific shelves. Extensive gravel deposits have been outlined north of Barmount Bay off the New Jersey coast (Schlee, 1968), within Massachusetts Bay, the Gulf of Maine, and on the Florida shelf (Rigg, 1974). Pings and Paist (1970) believe that the offshore sand and gravel industry is still in its infancy and will grow and develop extremely rapidly due to the abundance of suitable deposits in shallow water near markets and the relative ease with which materials can be recovered, classified, and transported by barge. This will be particularly true in the Boston to Norfolk megalopolis. Detailed studies are already underway in the coastal and offshore areas of most other coastal states to define the potential of these resources with the U.S. Army Corps of Engineers doing much of this work through the Coastal Engineering Research Center.

In addition to the massive needs of aggregate for the construction industries, another important use is emerging for the submarine sands and gravels. During 1973, millions of cubic yards of sand were pumped from Cape Hatteras, N.C., to the nearby beaches by the National Park Service. This major effort to replenish 2.2 miles of lost beach with sand is only temporary since shoreline recession in this area has averaged 9 meters per year for the past 100 years (Dolan, et al, 1973). This is becoming an ever increasing problem around the entire country as the rate of shoreline development spirals. The Corps of Engineers estimates that about 7 percent of the United States shorelines are experiencing critical coastal erosion while an additional 36 percent are experiencing slight to moderate erosion (1971). Where is the sand going to come from if the beaches are to continue to be replenished, particularly when the sand has to be of a certain grain size which is in equilibrium with that particular energy regime? This resource problem is a little more difficult than locating construction aggregate.

HEAVY AND LIGHT MINERALS

Many of the sand resources of the coastal area contain varying concentrations of heavy and light minerals that have significant economic value. The heavy minerals (minerals with high specific gravities) include the titanium and refractory minerals, zircon, monazite, and the less common minerals such as gold, tin, platinum, chromium, and diamonds (Table 2.). These minerals occur concentrated in placer deposits in drowned river channel deposits, modern beaches, and old beaches on both the adjacent coastal plain and continental shelf that were formed during fluctuations in the sea level. These minerals are commonly mined from similar types of deposits on the land, but rarely have they been successfully mined in the offshore zone. In spite of the lack of past economic development of these coastal deposits within the United States, heavy minerals are extremely popular and have been and are presently being extensively studied in the marine sediments in most coastal states. Many of these studies have been in connection with the heavy metals program of the United States Geological Survey, which was initiated in 1966 to stimulate domestic production of a small group of critical metals including gold. Some of these metals, such as gold, tin, platinum, and chromium, will probably be dredged from the United States sea floor in the near future simply because they are in considerably short supply. The Pacific shelf has known deposits of gold off California and Oregon, chromium off Oregon, and gold, tin, and platinum off the Alaskan coast.

The light minerals (minerals with average or less than average specific gravities) include pure quartz or high silica sand or feldspar-rich sands which can be used as a source of potash (Table 2.). Both of these commodities are of considerably less value than the heavy metals, and are very abundant on land; consequently, the potential of these commodities being economically extracted from the sands in the marine environment probably lies sometime in the future yet.

SHELL

Shell aggregate is commonly dredged from shallow estuarine waters and adjacent land areas in several portions of the United States coastal zone. The shell, mostly from old oyster reefs, is primarily used for aggregate in road building and concrete, the manufacture of Portland cement and lime, and in small amounts, for miscellaneous markets such as poultry

grit and cultch material for modern oystering. Generally, the total land resources of calcite ($CaCO_3$) in the United States are presently adequate. However, in local metropolitan regions, this resource is often unavailable or lacking; then transportation and land values again become the controlling factors and the estuarine shell deposits become an alternate supply.

The largest production of shell comes from the gulf coast states including Texas, Louisiana, Mississippi, and Alabama with lesser amounts produced in Florida and California. Some minor production has come from the mid-Atlantic states of Virginia, Maryland, and New Jersey. The State of North Carolina is presently carrying out a shell survey within some estuaries. Extensive shallow Pleistocene oyster reefs and marine shell beds underlie the estuaries and the mainland areas adjacent to the estuaries in northeastern North Carolina (Riggs and O'Connor, 1972). Since extensive limestone deposits outcrop along most of the North Carolina coast, the muddy shell deposits are only locally mined for landfill purposes. Most of the central and south Atlantic coastal states have a similar geologic setting with abundant limestone just inland from the coast. Consequently, the need for and the probability of developing the estuarine shell resources in these areas is minimal. The north Atlantic states have only minor shell deposits due to the occurrence of extensive glacial sand and gravel deposits throughout the coastal zone.

In contrast to the Atlantic coastal plain, the Texas coastal zone has limited limestone, gravel, and crushed stone reserves to supply the needs for constructional aggregate, cement, and the large chemical industrial complexes. These massive needs are supplied largely by the extensive shell dredging industry in the shallow Trinity, Galveston, and San Antonio Bays, about 75 percent of current production coming from the latter. The shell occurs as distinct reefs either at the bay bottom, which support living oysters, or buried at varying depths within the bay muds. Shell production began in the late 1800's and continued slowly until the 1950's, reaching peak levels during the last 15 years (Fisher, et al, 1973). In 1971, production began to fall off considerably, due to both rapidly diminishing reserves and increasing environmental pressures.

Clay

Clay is another low unit cost commodity critical to the construction industries and therefore is related to the metropolitan markets; thus, transportation costs and land values are again the critical parameters. Clay is primarily used in the ceramic industries for building bricks, refractories, tiles, et cetera. Since clay deposits are extremely common and widespread on the land there is little need to develop submarine clays. Nevertheless, clay is a major sediment type which is being deposited in the modern estuaries, as well as occurring in the older Pleistocene sediments. Riggs and O'Connor (1974) have described extensive clay wedges in the estuaries of northeastern North Carolina. The proximity of these clay deposits to the Norfolk metropolitan area which is a great distance from the nearest brick factories has provided some potential economic value to an otherwise noneconomic sediment. Similar Pleistocene clay deposits in the Myrtle Beach, S.C., area are presently being exploited as raw material for brick.

Peat

Extensive peat deposits commonly occur in the protected estuarine intertidal salt marshes and freshwater swamps. These low energy transitional zones from water to land represent areas of rich organic growth which produce the thick peat accumulation of partially decomposed organic matter. This peat is used in horticulture for soil improvement; however, this market is both local and somewhat limited. Consequently, most peat extractive industries are very small operations.

Total Sediment

Probably the most common form of extractive industry in the estuaries is the dredging of sediment for adjacent land fill and shoreline modification purposes, in which case the sediment itself has a low unit value. This whole category seems to be a very gray zone that nobody claims, acknowledges, or considers as a legitimate part of the minerals industries within any of the coastal states. This total sediment dredging includes everything from landfill itself to beach replenishment, ditching for mosquito control, drainage of marshes for agriculture and logging, stream channelization, harbor development, and finally, into channel dredging and maintenance. This extractive industry represents by far the greatest volume of material extracted directly from the estuaries. As a result, it probably has a far greater pollution impact upon the estuaries than all other forms of mineral extraction.

POLLUTION EFFECTS

The pollution effects resulting from the extraction of the surface sediments by mine dredging are no different than those from conventional channel and harbor dredging. In fact, the latter probably represents by far the single most important form of "estuarine mining" that takes place in our coastal waters. The subject of channel dredging is being treated in considerable depth independently within the study of estuarine pollution. In general, the pollution effects of the extraction of mineral resources from the surface sediments within the coastal zone can be summarized as follows:

1. Since there is often very little processing other than washing and sizing, surface sediment operations are less likely to contribute chemical pollution to the coastal system. Likewise, they generally contribute minimal amount of dissolved metals and substances to the coastal waters.
2. Extraction operations of surface sediments on the land areas adjacent to the estuaries can generally be carried out in shallow closed systems so that little deleterious sediment escapes into the coastal waters and there is minimal impact upon the groundwater system of the region.
3. On the other hand, the extraction operations within the estuarine waters can produce vast amounts of sediment pollution and have a dramatic impact on the physical-chemical character of the estuaries. More specifically, these include the following:

    a. Large amounts of sediment will be suspended producing increased water turbidity. This tends to decrease organic productivity by affecting light penetration and the resulting photosynthesis. More importantly however, these increased suspended sediments can drastically change the bottom sediment patterns and the resulting benthic floral and faunal populations. In a study by Riggs and O'Connor (1974) in the nearshore area off Pinellas County, Fla., the effects of the high amount of organic rich suspended sediments derived from landfill dredging in Boca Ciega Bay had a drastic effect upon the nearshore environments around John's Pass. The suspended sediments in the murky estuarine waters are pulled out of suspension primarily by "filter-feeding benthic organisms (mostly polychaetes) and excreted as fecal pellets which then accumulate in extensive ephemeral deposits." The resulting pelletal muddy sand populated by polychaetes is rapidly displacing the "more desirable" populations including the beautiful and extensive "sponge gardens" and associated invertebrate and fish populations which occur throughout this nearshore area.
    b. The removal of materials from the estuarine bottoms and the disposal of spoils produces great modifications of the bottom topography. Such changes have dramatic effects upon the remainder of the estuarine system which include circulation and the resulting water chemistry (salinity, dissolved oxygen, et cetera.) The deepening of the water and the steepening of slopes will also increase wave-induced erosion of the adjacent estuarine shorelines.
    c. In addition, these extraction processes produce temporary disruption of the productive habitat and oftentimes a permanent change in the type of habitat. For example, generally a greater area will have deeper water and steeper slopes after the dredging than existed prior to dredging, thereby producing a net loss of the more productive shallower water environments. This would result in major changes to the biological population inhabiting the area as well as a loss of the shallow breeding grounds.

4. Most extraction operations of the surface sediments on the continental shelves could probably be carried out with a smaller immediate and less far-reaching pollution impact upon the estuaries than direct estuarine mining itself. However, since there are so many variables such as geographic location, character of the sediment, local current system and energy levels, et cetera, each specific circumstance must be considered independently. For example, a recent effort to extract gravels from the shelf in Massachusetts Bay was temporarily halted because of the sediment dispersal patterns from the dredge site (Nelson, 1974).

In summary, the extraction of surficial deposits in the estuarine zone has extremely variable effects upon the estuarine system. Exploitation of land deposits adjacent to the estuaries should be allowed to fully develop to supply the local needs, however, only with strong controls for handling and discharging surface waters, effluent control, and reclamation. Exploitation of the vast potential resource wealth in the offshore area should be encouraged, but again, only with strong controls which allow each deposit or operation to be evaluated independently. On the other hand, extraction of the surface deposits within the estuary itself should not be allowed. The resources in the surficial deposits are usually stimulated by local economic development and are absorbed into the local urban development and do not spawn significant new industrial and

Table 3.—Relationship of type of mineral resource to the general resource value and cost of production within the coastal zone

Resource category	Examples	Mining method	Present status	Value	Cost
Surface Deposits				General increase in value of the resources available for exploitation ↓	General increase in cost of exploration and exploitation ↓
Unconsolidated to partially consolidated sediment	Sand, gravel, shell, etc.	Dredge	Abundant Production		
Consolidated rock	Crushed rock and limestone	Explosives and dredge	No Production (only for channel dredging, pipelines, etc.)		
Subsurface Deposits					
Pumpable materials					
Gases and fluids	Oil, gas, LPG	Drill hole (pumping)	Very Abundant Production		
Soluble solids	Sulfur, potash	Drill hole (solution mining)	Abundant Production		
Unconsolidated sediment	Phosphate	Dredge (island damming and open pit)	No Production (technology being developed)		
	Phosphate	Drill hole (slurry mining)	Moderate Production		
Consolidated sedimentary and crystalline rocks	Coal, iron, oil shales, metals (gold, silver, copper, etc.)	Hard rock underground mining methods	No Production (technology available for working from adjacent land areas or artificial islands)		

economic development. Also, most often these commodities can be replaced with other low unit cost alternative materials, including natural, manmade, and waste products. The short-term gains of low unit value materials cannot justify the increased pollution and modification problems in an already highly stressed system which plays such an important role in the productivity of the oceans.

Subsurface Deposits

The extraction of natural materials from the subsurface is a much more expensive operation which requires more sophisticated technology and equipment than the extraction of surficial materials. Consequently, the types of materials that can be recovered from the subsurface are the glamor commodities which include the fuels, the metals, and the higher unit cost non-metallic resources (Table 3.). The deeper in the ground or the further to sea one has to go to recover these commodities, the higher the cost and the more "glamorous" the material has to be. Also, the technical problems and the cost of recovery increases dramatically as we move from the materials that can be pumped to the surface, to unconsolidated sediments, to consolidated rock (Table 3.). These three categories represent a logical approach to discussing the extraction of specific materials and their resulting pollution potential upon the coastal system.

PUMPABLE MATERIALS

Quantitatively, the most important materials in this category are natural gas, oil, LPG, ground water, and geothermal energy. Because of the extreme importance and size of the extractive industries associated with these commodities, they will be considered separately in another report.

The other natural materials included here are the soluble solids which include sulfur, salt (NaCl), and the various potash minerals. All three of these materials are associated with evaporite deposits and the resulting salt domes, which are in themselves a very important reservoir trap for petroleum. Since salt domes commonly occur in the coastal zone and on the continental shelves, and because of the rapid increased exploration and development of offshore petroleum, the future increased extraction of these commodities in coastal areas is pretty much assured.

Presently, sulfur is the only soluble solid being produced from the coastal zone in the United States; however, salt and potash are being produced by solution mining from inland Canada. The presently known deposits of sulfur occur in the Texas and Louisiana estuarine zone, with present production coming from only one offshore area in Louisiana. The extraction of sulfur is from many wells located on fixed, above-water platforms. Utilizing the Frasch method of solution mining, the sulfur is then pumped through heated pipelines to processing plants on land.

The pollution problems associated with solution mining in the coastal zone can be summarized as follows:

a. The problems of leaks, breaks, and effluent (hot water, brines, drilling mud, et cetera) associated with solution mining and pipeline operation;

b. The problems resulting from the operation and maintenance of the big equipment associated with drilling, pumping, and transportation;

c. The most important problem, particularly with petroleum, of the allied industries which are established in nearby coastal waters.

UNCONSOLIDATED TO PARTIALLY CONSOLIDATED SEDIMENTS

This category would include any mineral resource that occurs in the subsurface in soft or unconsolidated sediments that are diggable. The major resources that presently fit into this category are phosphate and possibly coal and oil shale. Coal is mined from below coastal waters in many places around the world; however, in the United States the underwater coal potential does not appear to be very great and oil shale is probably down the road some. On the other hand, both the Atlantic and Pacific coastal waters have vast phosphate reserves which occur primarily in the subsurface with only small surface concentrations.

The outer coastal plans, estuaries, and nearshore shelf areas of North Carolina, South Carolina, Georgia, Florida, and California have tremendously large and extensive beds of phosphorite sediments that occur under from 10 to several hundreds of feet of overburden sediments. In Beaufort County, N.C., the Pungo River Formation is presently being strip-mined directly on the banks of the Pamlico River estuary. Three million tons of phosphate have been produced annually for the past eight years from a 50 foot bed below 90 feet of overburden. The operating company is presently doubling its plant capacity while another company has just recently announced its plans for opening a new mine next year. The projection for the new mine is to produce 4 to 5 million tons a year by 1977. The operating company controls 30,000 acres which contain over 2 billion tons of phosphate reserves. Of this, 10,000 acres occur on a state mining lease below the Pamlico River estuary. In fact, this very rich phosphate bed underlies not only several large counties in eastern North Carolina, but hundreds of square miles of the Pamlico Sound and Neuse and Pamlico River estuaries. The existing phosphate mining operation has had a very small direct impact upon the adjacent estuaries. Hobbie, et al (1972) reported that the addition of phosphorus in the estuary resulting from the adjacent phosphate mine was irregular, but small, producing only slightly higher concentrations than normal. The periods of high photosynthesis within the estuary are a direct function of nitrate fluctuations coming from upstream and not the phosphorus. There have also been only very minor effects upon the major fresh water aquifer directly beneath the phosphate bed, due to the need for heavy pumping to dewater the large open-pit mine.

Similar extensive subsurface deposits of phosphorite occur in the coastal areas extending from Charleston, S.C., to south of Savannah, Ga. An attempt by a major mining company in 1966 to mine part of the 7 billion tons of phosphate reserves occurring under the coastal marshlands and estuaries of Chatham County, just east of Savannah lead to a major study by the University of Georgia System (1968). This report studied the geology and economic potential of the deposit, as well as the effects of mining upon the ground-water system. Even though the report was generally favorable, mining was completely blocked by the environmental aspects of the potential open-pit dredge mining. Furlow (1972, p. 226) said that:

> . . . public opinion, aroused by conservation groups two years ago, is still so adamantly opposed to mining marshland and disrupting ecological chains that I can foresee no time in the future when marshland mining will be allowed. These conservation groups have only to point to phosphate mining areas in Florida as prime examples of what would happen to the Savannah area.

Drill hole information from the Georgia Department of Mines, Mining, and Geology suggests that the Chatham County deposit extends offshore at least 10 miles and possibly as much as 20 miles with small overburdens, high grades, and large tonnages. Furlow (1972, p. 228) concludes that the:

> . . . future of phosphate mining in Georgia lies entirely in the offshore area rather than in the marshlands. Offshore dredge mining, while more difficult and expensive than onshore mining, can be accomplished with present or presently developing technology. Last, but certainly not least of mining considerations, conservation and ecologically-oriented groups would have far less objection to offshore mining than they would to mining in the unspoiled marshes of Chatham County.

The California Continental Shelf also has extensive deposits of phosphate sediments. In fact, these deposits were planned for development in 1961; the United States Geological Survey subsequently sold its first and only hard mineral lease on the continental shelf in April 1974 (Rigg, 1974). However, this sale involving six tracts and totalling 30,000 acres, was subsequently cancelled by the United States Geological Survey when it was learned that there was a World War II munitions dump on the lease site.

The exploitation of the unconsolidated sediments from the subsurface generally represents tremendous earth moving operations utilizing open-pit strip mining techniques with massive equipment. Vast acreages are involved in both recovering the extensive beds of reserves and treating and disposing of

the waste materials. It has been demonstrated in North Carolina that such operations can safely take place on the lands adjacent to the estuaries with only very minimal pollution and direct environmental impact upon the estuaries. However, similar mining operations in central Florida, 20 to 50 miles inland from the coastal zone, have been extremely damaging to the estuaries; upon occasion the wall of a slimes pond will fail, sending millions of tons of mud downstream.

Similar types of mining operations are technically feasible within the estuarine waters; the shallow waters can be filled, or even diked and drained allowing for either open-pit dry mining or underwater dredge mining. However, due to the extremely large land requirements, the vast amounts of earth movement, and the problems of the resulting waste materials, there is a tremendous permanent modification of the estuarine environment and system. Also, a great potential exists for massive estuarine damage resulting from broken dikes during major storms and storm tides.

Offshore mining of these deep phosphate reserves is technologically and economically questionable at the present time. The two greatest factors are probably the high energy levels of the Atlantic and the economic factors of ore dilution with dredge mining. With respect to the potential effect upon the adjacent estuarine systems, each situation would have to be individually evaluated as with offshore surface mining.

The technology which would allow surface mining of phosphates utilizing a subsurface pumping method is actively being tested on the deep phosphate deposits in North Carolina. If this pumping procedure can be adequately developed, it could provide a satisfactory alternative to open-pit mining for recovering the vast estuarine and offshore phosphate deposits with minimal estuarine damage.

CONSOLIDATED ROCK

Because of the high cost of hardrock mining in the subsurface, the only potential mineral resources that can be economically considered in this category are the glamor metals (gold, silver, copper, lead, zinc, et cetera) and the fuels such as coal and radioactive minerals. Extensions of underground mines from adjacent land areas have been producing about 30 million tons of coal per year from under the sea in eight different countries for a long time (McKelvey, 1974). The fact that there are at present no such undersea mines in the United States does not indicate the potential. Since the continental shelves are merely the submerged portion of the continents, they can be expected to contain similar mineral resources as the continents. For example, a copper and zinc deposit below the tide flats of Penobscot Bay in Maine was originally mined from three underground shafts (Smith, 1972). More recently, a 90-acre salt marsh was dammed and drained for a short-lived open-pit operation. The environmental pollution problems included salt water encroachment into the fresh water aquifer, silting and water turbidity, and heavy metal contamination in the estuary.

Technology presently exists for mining below the estuary from shafts on the mainland or from man-made islands within the estuary. The technology already exists for using a lock tube seated in a shaft cored by a big-hole drill supplying vertical hole entry with an open air underground mine. This would allow for the use of the same mining techniques as used on land (McKelvey, 1968). To date, this technology has not been put into operation in the nearshore ocean environments. This, however, is not too far in the future. Moore (1972) believes that the technology will exist and the need will be great enough to support large-scale mining of noble and base metals from the shelf by 1980 with almost total dependence upon this source by the year 2000. A pretty firm basis has already been well established for such a prediction—the present transition of the major petroleum reserves to the coastal and offshore shelf environments. Another important factor that is involved here is that at present only a very small percentage of the coastal and inshore shelf has been explored for anything other than petroleum.

The potential impact upon the estuaries of subsurface hard rock mining on land is extremely variable and is only partially dependent upon its proximity to the estuary. Regardless of its location, resulting heavy metal contamination of the estuarine waters and bottom muds is common. On the other hand, those operations which are in close proximity to the estuarine system could also have a more direct impact upon both the groundwater and estuarine waters.

POLLUTION EFFECTS

The potential pollution impact resulting from subsurface mining within the estuary and nearshore environments is probably not as great as surface mining in the same areas would be. This type of extractive operation would cover smaller areas, move smaller volumes of material, and would not be directly connected with the water column, which means that it generally would be a cleaner operation. The major impact would be associated with the

barge transportation of the ore and the necessary processing plants located on the nearby coastal area. The potential chemical and sediment pollution resulting from hardrock-metal beneficiation plants and smelters is generally very great.

Aqueous Deposits

Most of the elements known on the earth's surface can be found in seawater. These various chemical constituents comprise an impressive 165 million tons of dissolved solids per cubic mile of sea water in the world's oceans. This amounts to a total mineral reserve of 50×10^{15} tons for the 330 million cubic miles of sea water, thus forming the largest continuous ore body available to man (Shigley, 1968). However, the concentration of most of the elements is so low that only very few are presently and probably will be economically exploitable in the near future. Four groups of commodities are presently being extracted, or recently have been extracted, from sea water in the United States; these include the chlorides (including common salt), the magnesium compounds and magnesium metal, bromine, and water. In addition to these, the ocean waters may some day yield the most important source of energy for the long-term solution to the ever-increasing energy needs—deuterium. Deuterium is a heavy isotope of hydrogen useable in the process of fusion; the ocean waters contain 25 trillion tons of deuterium (McKelvey, 1974)—so much that only 1 percent would supply about 500,000 times the world's initial supply of fossil fuels; the total could supply the world's energy needs for 120 million years at 40 times the 1968 level. (Holdren and Herrera, 1971.) It also appears that deuterium can be extracted from sea water without any ill effects upon the water and biological system.

Technological processes have been developed for recovering all of the major elements and many of the minor elements dissolved in sea water. However, only four groups of materials are presently being economically extracted on a large scale. A brief discussion of each of these groups follows.

Sodium and Calcium Chlorides

These two commodities are presently being produced by solar evaporation behind extensive diked flats in the estuaries of San Francisco Bay, Calif. Recently, salt was also produced in similar evaporation flats in Newport and San Diego Bays, Calif. However, due to the extensive acreages of estuarine flats necessary for this operation and the extreme urban pressure for development, the latter two have closed. It is not likely that future fields will be opened since salt is readily available from brines, rock-salt mines, and as byproducts of potash mining. The environmental pollution resulting from the salt operations is very poorly known and is generally thought to be minimal. This is pointed out by the recent establishment of a National Wildlife Refuge in San Francisco Bay which includes 12, 243 acres of salt company lands, most of which is used for salt production. The company has been assured, however, that continued salt production is considered compatible with the Refuge (Davis and Evans, 1973). However, the diking of the estuarine flats, along with the resulting bitterns from the salt operations, definitely does modify the geometry, chemistry, and the biota of the coastal environment.

Magnesium Compounds and Metal

Many of the various compounds of magnesium produced in the United States are derived from sea water in eight coastal plants operating in six states (Table 4.). The remainder of the magnesium is produced from well brines and magnesium minerals. The process involves adding the sea water to lime solutions, forming a magnesium hydroxide precipitate. The lime is generally derived from oyster shells which are dredged from the estuaries. Magnesium metal is also produced from sea water at the Dow Chemical Company plant in Freeport, Tex. In 1972, they produced 120,000 short tons of metal utilizing chemical and electrochemical processes. The production of the magnesium compounds itself produces very minor estuarine pollution; however, since the production of the metal is a chemical process, it has a greater potential chemical impact upon the estuarine system.

Table 4.—Domestic producers of magnesium compounds from sea water in 1972 (from Minerals Yearbook for 1972, United States Department of the Interior, Bureau of Mines, v. 1, p. 748)

Company	Location	Capacity (short tons MgO equiv.)
Basic Magnesia, Inc.	Port St. Joe, Fla.	100,000
Barcrott Company	Lewes, Dela.	5,000
Chorchem, Inc.	Pascagoula, Miss.	40,000
Dow Chemical Company	Freeport, Texas	250,000
FMC Corp.	Chula Vista, Calif.	5,000
Kiser Aluminum & Chem. Corp.	Moss Landing, Calif.	150,000
Merck & Company, Inc.	S. San Francisco, Calif.	5,000
Northwest Magnesite Company	Cape May, N. J.	100,000
		655,000

BROMINE

This element was economically produced from seawater in combination with other extraction processes. For example, in 1967 the Dow Chemical plant in Freeport, Tex., produced large amounts of bromine as a byproduct of magnesium extraction. Also, the solar salt pans at Newark, Calif., produced bromine as a byproduct of the evaporite bitterns. These extraction operations required chemical plants located directly at the water's edge and, therefore, produced minor amounts of chemical pollution. However, by 1971, all of the bromine produced in the United States was from well brines in Arkansas and Michigan and lake brines in California (United States Department of the Interior, 1973).

WATER

The desalinization of seawater to produce usable fresh water is an old idea that is becoming increasingly important in the world today and locally it is even becoming an economic extractive industry. In 1966, there were 153 seawater desalinization plants in the world with daily capacities greater than 24,000 gallon per day (Shigley, 1968). He believes that: . . . "the rate of growth of desalinization has been about 30 percent per year for the past 10 years; it is now predicted that the installed capacity will be about one billion gallons per day by 1978."

Since 1958, when the United States Office of Saline Waters authorized the construction of five pilot plants to test different desalinization processes, three coastal based plants have been desalinizing seawater. These plants are located at Wrightsville Beach, N.C., Freeport, Tex., and San Diego, Calif. Today the costs of water production in these specific plants averages between 75 cents to $1 per 1,000 gallons as compared to the average freshwater costs of 30 to 35 cents per 1,000 gallons for industrial and municipal use and about 5 cents per 1,000 gallons for agricultural uses (Cargo and Mallory, 1974). Since the effluents of desalinization are more valuable as a source of minerals than the average seawater, the development of the necessary technology could play an important role in changing the economics of the entire extractive industries from ocean water, including fresh water. Indeed, due to increasing demands for limited ground water plus the rapidly increasing pollution of our water resources, these plants will become more important and abundant in the near future.

Several critical areas in the United States where desalinization could become economic very soon are portions of South Florida, the Outer Banks of North Carolina, South Texas, and Southern California. Consequently, the estuarine impact of this extractive process will only increase with time in the United States. The impact resulting from the effluents derived from desalinization is local and relatively small as compared to other extractive industries. The effluents are about equal in volume to the amount of fresh water produced, and they have about twice the concentration of the original seawater (Shigley, 1968). Of far greater impact is the associated urban, industrial, and agricultural development that would follow, particularly in the areas that presently are deficient in fresh water resources.

POLLUTION EFFECTS

The environmental impact of those industries extracting from aqueous deposits upon the associated estuarine systems appears to be less than some of the other extractive industries. Since these are land based operations, the physical intrusion is limited to the adjacent shoreline area. However, all of the extractive industries described in this section produce brines with increased heavy metal contents, often heat, and in some cases chemical effluent. Discharge of these effluents, unless properly monitored and controlled, could produce significant local estuarine pollution. Probably the greatest impact that this group of extractive industries has upon the estuarine system is indirect, resulting from the stimulation of and interdependence upon numerous other industrial, commercial, and residential activities. Shigley (1968), pointed out that the combination of raw materials and location at Freeport, Tex., has stimulated the development of a large chemical manufacturing complex, of which seawater processing activities are only a part. Because the seawater processing activities share raw material overhead, and research with over a 100 other products in such an industrial confine, what would otherwise be either a marginal or uneconomic operation, can become economic and viable.

CONCLUSIONS

The relationship between mineral resource utilization and the coastal system is presently and will continue to produce an ever-increasing dilemma with respect to estuarine pollution. This basic dilemma can be summarized with the following conclusions:

1. Our growing technological society is totally dependent upon a myriad of basic mineral resources which are the raw materials for the technical machine. The value of, and demand for any of these basic

resources is dictated by the industrial technology and economic considerations at any given time, both of which are highly changeable and volatile controls.

2. Extraction of minerals has to take place where the minerals occur; the location of resources cannot be legislated or decreed. Since the coastal zone does contain a myriad of potential resource commodities necessary for our technological society and since these commodities do have an economic value, society demands exploitation.

3. Even though there is considerable mineral resource potential within the coastal zone, there is a dramatic lack of information pertaining to the occurrence, distribution, and concentration of specific materials. This is absolutely essential information which is prerequisite to any form of coastal zone management.

4. The potential environmental and pollution problems associated with resource extraction, preparation, and transportation, which are prerequisite to their use, are often exceedingly great. The processes of extraction of these resources are often messy operations that are capable of physically, chemically, and biologically disrupting and/or modifying the fragile coastal and estuarine system. The resulting effects may be either direct or indirect, local or broad scale, temporary or permanent, and of varying degrees of severity, all depending upon the commodity itself and the methods of extraction and processing. In addition, a myriad of satellite industries develop in the coastal zone in response to a given extractive industry; often these industries have a greater potential cumulative impact upon estuarine pollution than the extractive industry itself. Some extractive and satellite industries are not compatible with other legitimate uses of the estuarine system.

5. Some resource materials have alternate sources from which the necessary raw materials can be supplied and many have substitute materials that can be made available or developed. This is particularly true of the low unit cost aggregate materials. Other materials, however, do not have alternate sources or substitutes. Consequently, attitudes towards and necessity for the recovery of the mineral resources within the estuaries and offshore areas vary between the two opposite extremes of complete abstinence to complete development.

6. The estuarine system of the United States occupies a very narrow transitional zone between the land area and the continental shelf; the total extent of this system represents an extremely small but manifestly important percentage of the United States. The estuaries, for the most part, are the terminal mixing basins of the freshwater drainage systems with the ocean's waters. Therefore, they receive the cumulative residue, waste, pollution and sediment resulting from all man's and nature's activities within each drainage system, subsequently funneled into the estuaries.

7. Socially, industrially, and demographically, the United States has evolved, in a manner that appears to be continuing, with disproportionate concentrations within the coastal zones. This continual encroachment and the mounting intensity of development and use of the estuarine zone has produced a highly stressed system which is resulting in major and potentially devastating changes within this fragile and important transitional area.

If one can accept these statements as valid, then there is no alternative but to establish a moratorium on all estuarine activities that will continue to add stress to an environment that represents such a vital part of the earth system and which presently sits in a very precarious balance. The extractive industries, to a large extent, fall into this situation. Development of the mineral resources on the adjacent lands and the offshore continental shelf areas should be encouraged with the proper setback lines from the shore, environmental controls, and a viable monitoring system. However, the question of mineral extraction from within the estuaries themselves should be seriously reevaluated. The age old question of which is the most valuable to man, provokes the honored response—the old "trade-off" game. But as man's needs grow, the "trade-offs" grow and pretty soon we're "trading off the trade-off." Man can no longer afford this sort of approach to the continued development of some small part of the system which in its totality is a critical resource that has well defined limits. The need is to start evaluating the natural systems, upon which man is so dependent, from a long-term basis of interdependence and not the immediate short-term dollar value. Multiple use and estuarine management are fine concepts that satisfy quarreling factions, but all too often they amount to little more than a sophisticated land grab—like the old miners staking their claims. One must approach the continued use and development of the estuaries as a single complex interacting ecosystem which has finite limits—these limits must be defined now.

RECOMMENDATIONS

In order to meet the objective of the overall study considering the status of pollution in the nation's estuarine zone with respect to the mineral extraction

processes, I propose the following recommendations:

1. Establish a moratorium on any further development of the extractive industries within the estuaries until the proper background resource information can be obtained to set up a viable management program. After a national resource priority base has been developed, establish stringent sets of procedures that define what resources can be extracted from the estuarine system, where, and by what methods.

2. An extensive and exhaustive study should be initiated by Congress and placed under the direction of the U.S. Geological Survey, to map the geology and inventory the mineral resource potential of the United States coastal zone in a similar fashion to the extensive U.S. Geological Survey-Woods Hole Atlantic Continental Shelf study or the U.S. Geological Survey heavy metals study. Such environmental and geologic mapping is an absolutely essential first step for any resource management program which will consider the multiple use by conflicting interests. One cannot plan the destiny of a system without an intimate knowledge of the composition and processes operating within the system. Use evaluations and trade-offs cannot be made until the total resource potential is known.

3. A mechanism should be set up within the geological surveys in the coastal states under the direction of the U.S. Bureau of Mines to monitor the extractive industries within the coastal zone of their state. This monitoring system should include: (a) the volume and values of annual production and the reserve situation of each specific mineral commodity; (b) the extraction methods and disruptive effects of each specific mining operation upon the estuarine system; and (c) the processing and transportation methods of each mining operation and its actual and potential disruptive impact upon the estuarine system.

4. Establish rigid stress limits to stabilize the disproportionate growth and development of the estuarine systems throughout the United States. This should include delineation of the type as well as the amount of growth and development.

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FISHERIES

STATUS OF ESTUARINE ECOSYSTEMS IN RELATION TO SPORTFISH RESOURCES

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ABSTRACT

Increasing numbers of anglers—ten million at this time—fish along the coastal shores, an estimated 57 percent of them in the estuaries. Factors affecting the ecosystem are discussed. Recommendations are made to meet management needs, on the federal, state, and local levels.

INTRODUCTION

Ten million American anglers fish in coastal waters; they catch nearly one and a half billion pounds of fish each year. This massive recreational activity is supported by fish resources that are dependent on the continued health of estuarine and coastal ecosystems.

The number of people fishing in coastal areas has increased 50 percent since 1960, while the average yearly catch per angler has declined somewhat. The causes for the decline in catch—an indicator of fish population size—have not been determined with acceptable scientific validity and because of the environmental complexities of coastal ecosystems they may never be. In the following account we have had to work with skimpy circumstantial evidence to explore the causes and effects.

All in all, marine fish resources appear to be in surprisingly good shape. Atlantic stocks are improving after a period of general depletion during the 1960's. This may in part reflect the results of the recent national effort to clean up our waters and protect the environment. Further gains will depend upon how well fish harvest management and ecosystem protection can be combined into effective federal, state and local programs and how well societal goals for use of the resources can be defined and implemented.

THE COASTAL SPORT FISHERY

The ten million coastal anglers spread their efforts rather evenly along the U.S. shoreline, as shown for 1970 in Table 1, the latest year of record (from the National Marine Fisheries Service).[1] While there is reason to believe that the catches may be somewhat over-estimated by the inherent biases in the angler interview-recall system used, they can be assumed to give a reliable indication of the distribution of catches.

Anglers fish in both estuaries (tidal rivers, bays, lagoons, sounds) and oceans (surf and offshore waters), with 57 percent of the fish taken in estuaries. They spend about $100 each on fishing gear and other expenses per year.[2]

Coastal angling is a widespread attraction. Half the anglers have family incomes of less than $10,000 (1970 data).[2] Twenty-two percent are women. Most come from rural areas, towns, and suburbs rather than from large cities.

National surveys in 1960, 1965, and 1970, show that coastal fishing has increased by 50 percent in the span of one decade.[1,2] As the number of anglers increased from 6.2 to 9.4 million, the yearly average catch dropped from 102 fish to 87 fish per year per angler. This reduction is most likely a consequence of reduced carrying capacity of fishing waters, a possible natural reduction of fish stocks, or more fishing pressure on the stocks than can be accommodated at the same high catch rate.

The national sport-fishing surveys are not adequate to provide a statistical basis for examining trends in abundance because they are done so infrequently (5-year intervals) and because they contain inherent biases typical of poll (interview-recall) systems of data collection. A somewhat more sensitive indicator of abundance trends is the commercial catch which is recorded by the National Marine Fisheries Service through collection and tabulation of dealers' records. Example trends shown by commercial catch records are depicted in Table 2 for

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Table 1.—Estimated number of anglers and catch for 1970

Region	Number of anglers	Catch (millions of fish)	
		Ocean	Estuary
North Atlantic	1,700,000	35.3	81.7
Middle Atlantic	1,800,000	69.5	98.7
South Atlantic	1,800,000	112.2	72.0
Eastern Gulf of Mexico	1,500,000	42.4	146.6
Western Gulf of Mexico	900,000	47.2	50.5
South Pacific	900,000	34.7	2.5
North Pacific	1,300,000	8.3	15.8

four of the major Atlantic and Gulf of Mexico sport fish species.

The pattern is different for the various species, reflecting differences in biological, environmental and economic factors that affect their populations and their fisheries. Common to all, however, is a low point in catch in the late 60's, centering in 1967, followed by an upward swing into the 1970's, a trend not discernible in the 5-year national surveys of sport fishing catches (Table 3).

It is quite possible that the upswing of the latter 60's is partially due to a general lessening of pollution impacts and an improvement in water quality in coastal areas. For example, Edwin Joseph suggests that the increase in sea trouts may have been caused by decreasing agricultural use of DDT.[3] After World War II, DDT use rapidly increased in shorelands draining into estuaries where the spawning and nursery areas of the sea trouts are located. Lethal doses of DDT lodge in the yolk oil of many species causing death to embryos. Then after the middle 60's DDT use began to drop off. As it did,

Table 2.—The total commercial catches of certain estuarine dependent species groups for the Atlantic and Gulf States combined. (Source: National Marine Fisheries Service; 1972 statistics are preliminary)

Year	Millions of Pounds			
	Bluefish	Croaker	Flounder	Sea trouts
1955	4.2	47.3	63.4	16.4
1956	4.1	56.8	65.1	15.5
1957	4.8	19.0	69.3	14.1
1958	3.3	24.7	77.3	12.8
1959	3.8	11.9	75.0	10.6
1960	3.5	6.9	79.4	9.9
1961	3.7	5.2	85.5	10.2
1962	5.9	3.3	104.5	10.0
1963	5.9	2.7	125.5	9.3
1964	4.6	2.5	129.0	10.1
1965	5.0	3.5	133.7	11.9
1966	5.5	3.4	127.7	10.7
1967	4.3	2.5	112.5	9.5
1968	5.4	4.7	114.0	12.0
1969	6.0	6.7	115.0	11.4
1970	7.2	8.4	123.0	14.9
1971	5.6	10.6	125.0	18.7
1972	6.3	16.6	128.0	21.0

Table 3.—The estimated total U.S. angler catch of certain estuarine dependent species groups for Atlantic and Gulf States combined.[1] Catch in millions of fish

Year	Bluefish	Croaker	Flounder	Sea trouts
1960	23.8	46.0	50.6	83.8
1965	31.0	51.0	54.6	89.4
1970	36.0	66.0	57.4	107.0

breeding likely was restored to normal. Reduction of other chemical and industrial pollution is undoubtedly a factor in recent fisheries improvement.

Although these improvements are encouraging, many threats remain; vigilance is necessary, and a much higher potential is realizable. This potential is particularly high for reducing damage from effects such as urban drainage and physical destruction of estuarine systems, effects that do not originate with point source pollution (pipe discharges). To correct these, there usually must be control of land uses in the watersheds and along estuarine shores coupled, of course, with the control of point discharges. Such combined land and water ecosystem management programs are necessary to maintain the vitality of estuarine fish populations.[4]

THE ESTUARINE ECOSYSTEM

An estuary is a constricted coastal water body that connects to the sea and has a measurable quantity of salt in its waters. For management purposes, the following rule of thumb, which is based upon the degree of confinement, may be used to distinguish between estuarine and open coastal areas: An estuary is a waterbody that has a basin circumference in excess of three times the width of its outlet to the sea.[4]

The exceptional natural value of the estuarine ecosystem comes from a beneficial combination of physical properties that separately or in combination perform such functions as those listed below[4]:

1. *Confinement*: Provides shelter which protects the estuary from wave action, which allows plants to root, clams to set, and fragile small animals to exist; and permits retention and concentration of suspended life and nutrients.
2. *Shallowness*: Allows light to penetrate to plants on the bottom; fosters growth of marsh plants and tideflat biota; encourages water mixing; and discourages large oceanic predators which avoid shallow waters.
3. *Salinity*: Freshwater dilution deters ocean predators and encourages estuarine forms; precipitates sediments; and provides buoyancy and physiologically beneficial salt concentrations. Freshwater flow

over saltier, bottom water typically induces beneficial stratified flow.

4. *Circulation*: Tidal and wind forces plus stratified flow set up a beneficial system of transport for suspended life, enhance flushing, and retain organisms in favorable habitats.

5. *Tide*: Tidal energy is a major driving force of circulation; tidal flow transports nutrients and suspended life, dilutes and flushes wastes; tidal rhythm acts as a regulator of feeding, breeding, and other functions.

6. *Nutrient storage*: Trapping mechanisms store large amounts of nutrient within estuary; marsh and grass beds store nutrients for slow release as detritus; richness induces high accumulation of available nutrients in animal tissue.

About two thirds of the Atlantic and Gulf of Mexico species of coastal sport fish depend upon the special life giving properties of the estuaries for sanctuaries, or nursery areas for their young. Fewer Pacific than Atlantic species are critically dependent upon estuaries.[4]

The estuarine dependent species include those that spawn in the ocean, along the beaches, in the inlets, within estuaries, and up the tidal rivers. The young of all these converge in the estuaries for food, refuge, and suitable water. Most estuarine dependent fishes are ocean or coastal migrants who spend only part of their lives in the shallow estuaries. But this one period may be the most crucial part of the survival of the species. Three major categories of estuarine dependency are shown below with examples for each species:[5]

Adults found mostly in the estuaries, some only seasonally.	*Adults found partially in the estuaries, some only seasonally.*	*Adults found mostly along the open coast.*
Flounder (winter flounder)	*Striped bass (rockfish)	Bluefish
Spotted trout	Fluke (summer flounder)	Tautog (blackfish)
Tarpon	Porgy (scup)	King whiting (kingfish)
Croaker (hardhead)	Red drum (redfish or channel bass)	*Alewife (river herring)
Snook (lafayette)	Black drum	*Shad
*White perch	Mullet	Atlantic mackerel
		Menhaden (bunker, pogy)

* Anadromous species: Living as adults in salt or brackish water but spawning in fresh or nearly fresh water.

Estuaries and their adjacent shorelands are easily accessible for urban or industrial development. Use pressures are heavy in urban areas adjacent to estuaries and the pollution potential is high. The confinement and shallowness of estuarine water basins allow pollutants to pervade their waters, particularly those that have poor flushing characteristics.

There is irony in all this. The most urbanized estuaries which often suffer the highest environmental stress are at the same time potentially subject to the highest sport fishing demand because of the human populations concentrated there. Therefore, the very water bodies that should carry the greatest sport fish resources may actually carry the least.

Because of the variety of man-caused disturbances that affect estuarine waters and because of year to year natural changes in the environment that affect species, it is nearly impossible to establish any scientifically valid correlation between the type of pollutant, or other disturbance, and the status of any fish population. There does not exist in the scientific literature one scientifically convincing cause and effect relation between a single disturbance and a single effect. Therefore, one must look broadly at complete ecosystems in all their complexity and try to judge the multiple effects of multiple disturbances upon carrying capacity limiting factors.

CARRYING CAPACITY LIMITING FACTORS

The potential fish yield of any estuarine water body is governed by its carrying capacity for the species it supports. Carrying capacity in the strict scientific sense is the number of a particular species that can be supported per acre, or other measure of size. However, we use it here in a more general sense as the amount of life that a habitat can support.

Exactly what makes good fishing waters has always been a bit of a mystery. However, science has unraveled enough of the mystery to understand what environmental disturbances degrade good fishing waters and generally how they do it. Each type of disturbance reduces carrying capacity in a specific way and a combination of them causes a combination of carrying capacity reductions.

The National Pollutant Discharge Elimination System (NPDES) and related provisions of the 1972 Water Act should provide adequate control of disturbances arising from point sources of pollution (pipe discharges) including industrial and municipal wastes by the mid-1980's. This alone should considerably improve the carrying capacity of estuaries for fish. But controlling point sources is only part and perhaps the easiest part of the much larger job of restoring the carrying capacity of the nation's estuaries. Controlling non-point pollution may present a far greater challenge. For example, a primary source of non-point pollution discharge to estuaries

is urban runoff—water from city streets, industry sites, parking lots, and other developed areas—which often carries massive loads of pollutants into estuaries. The following amounts might be expected from a typical city of 100,000 population following a one-hour storm (in lb./hr.):[6]

	Street surface runoff	*Raw sanitary sewage*	*Secondary plant effluent*
Suspended solids	560,000	1,300	130
BOD_5	5,600	1,100	110
COD	13,000	1,200	120
Nitrogen (Kjeldahl)	800	210	20
Phosphates	440	50	2.5

Erosion from disturbed land surface often produces massive amounts of sediment that may be transported to estuaries, as shown by the following estimates:[7]

Activity	*Sediment Produced (tons/sq.mi./yr.)*
Construction	48,000
Cropland	4,800
Grassland	240
Forest	24
Disturbed Forest (not clear-cut)	24,000
Active Surface Mines	24,000
Abandoned Mines	2,400

This erosion may also bring excessive nutrients, toxic matter, and bacteria down to the estuaries to reduce carrying capacity for sport fish populations.

In the following sections we first describe each major natural factor that limits the total carrying capacity of an estuarine fish habitat. Second, we discuss the point and non-point pollutional disturbances that lower carrying capacity. And third, we relate the disturbances to specific human activities.

Oxygen

Of the various gases that are found dissolved in coastal waters, oxygen is of the most obvious importance to fish and other animal life. They need ample oxygen to survive and even more to grow and function well—the federal water standard is a minimum of 4.0 ppm (parts of oxygen per each million of water).

When sewage and other wastes with high BOD (biochemical oxygen demand) pollute coastal waters, bacteria multiply to enormous abundance and deplete the water of oxygen faster than it can be replaced by either plants or the atmosphere. Fish may be killed by a sudden oxygen drop but more often the problem is a persistent and pervasive lack of oxygen which reduces carrying capacity and repulses fish. For example, low oxygen from industrial and municipal wastes has eliminated striped bass spawning in the Delaware River and oxygen depletion from papermill waste disrupted salmon runs in Bellingham Bay, Wash. Oxygen levels are depressed to low levels in Florida canals built for seaside housing developments where fine sediments accumulate and water becomes stagnant—a half pound of organic wastes per day (e.g., grass clippings) is enough to contaminate a 100-foot length of canal, reducing oxygen from an acceptable 4.5 to an unacceptable 3.8 ppm.[9] In August 1971, all bottom fish deserted the western part of Long Island Sound around Glen Cove because of oxygen depletion caused by pollution.[10]

Temperature

Temperature controls life in the coastal ecosystem. Migration, spawning, feeding efficiency, swimming speed, embryological development, and basic metabolic rates of fish are controlled in large part by temperature. Temperature increase, such as that caused by power plant effluents may disrupt these basic life processes. (Power plants also suck fish in with cooling water and kill them in the pumps and pipes.) Where multiple power plants are placed on an estuary, temperatures can increase to damaging levels over extensive areas, such as the striped bass breeding grounds shown in Figure 1 or the vital grass bed nursery area shown in Figure 2 where 91 percent of the grasses were killed.

Fresh Water Inflow

The volume of fresh water supply not only governs the salinity of estuaries, but also controls circulation patterns (circulation strongly influences the abundance and the pattern of distribution of fish and other life in the estuary).

Some fish require different salinities at different phases of their life cycle such as those provided by runoff, summer drought, et cetera. Alterations affecting freshwater inflow may upset the natural salinity regime, upsetting habitat conditions to which the fish are naturally adapted and lowering carrying capacity. Salinity throughout the coastal ecosystem fluctuates primarily with the amount of dilution by freshwater inflow and the extent of evapotranspiration. The inner ends of estuaries may become so salty in summer when fresh inflow water is diverted for other uses that the water becomes

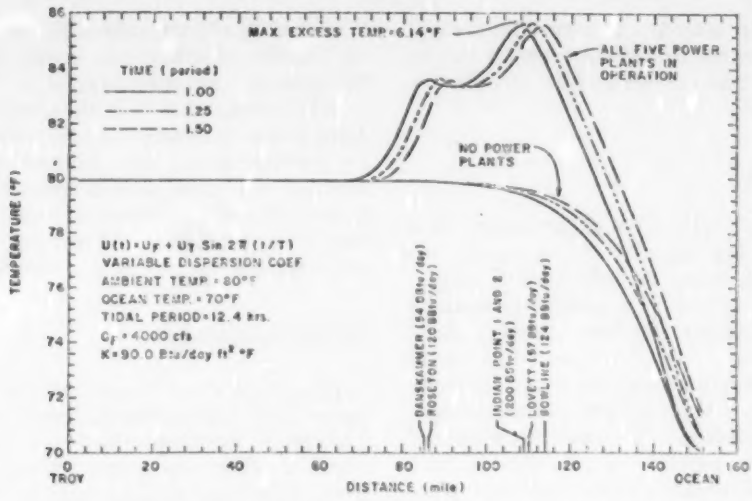

FIGURE 1.—Temperature of the Hudson from Troy, N.Y., to the ocean at three tidal times with five power plants in full operation.[11]

virtually uninhabitable for sport fish—for example, Tomales Bay, Calif. (39 ppt salinity),[13] and Rookery Bay, Fla., (to 40 ppt).[14]

Sedimentation

Also related to the volume of runoff inflow is the amount of sediment carried down into the estuary. Uncontrolled development in estuarine watersheds creates adverse effects by reducing the capability of the land to filter and hold back storm water runoff and to cleanse it of sediments as well as nutrients and a wide variety of other contaminants from the land surface. Therefore it is a fundamental goal of estuarine resource management to protect water bodies against excess loading of polluting materials by achieving control of damaging activities in the watershed.[4]

Accumulation of sediment on the bottom of an estuary results in shoaling of the basin and the creation of a soft, shifting, and basically unsuitable habitat for bottom life. These sediments also trap pollutants that are harmful to water quality when resuspended by wind, currents, or boat traffic. Virtual elimination of bottom life—as has now happened in the New York Harbor estuary—seriously degrades the ecosystem and dismantles the food chain of fishes.

An example of gross pollution from agricultural drainage and clearing is the estuarine system of Back Bay, Va., and Currituck Sound, N.C., which was loaded with silt which killed bottom vegetation, created high turbidity, and lowered the carrying capacity.[15] Sedimented and degraded estuaries with reduced carrying capacity for sport fishing are found along all sections of the U.S. coastline.

Corrective measures require control of: (1) erosion from land clearing and site preparation in the water-

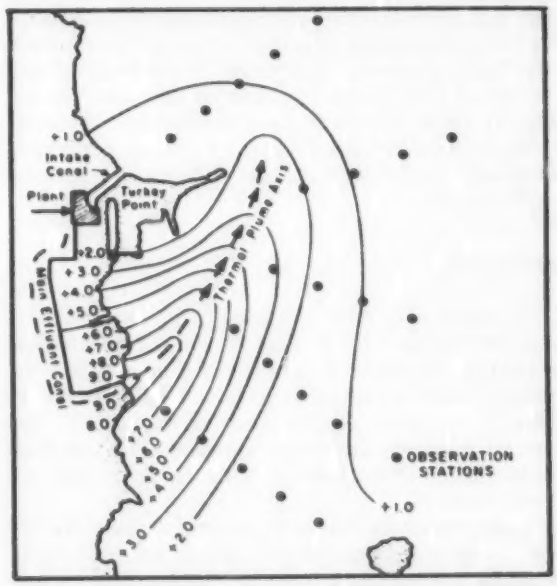

FIGURE 2.—Profiles of isotherms above ambient (°T) in Biscayne Bay during summer—the Turkey Point plant was subsequently fitted with an alternate cooling system.[12]

shed; (2) dredging activity in estuarine basins; (3) municipal and domestic pollution which creates organic sediments; and (4) boat traffic (which resuspends sediments).

Water Circulation

The circulation of water through an estuary is a key factor in carrying capacity. It transports nutrients, propels plankton, spreads "seed" stages, (planktonic larvae of fish and shellfish), cleanses the system of pollutants, controls salinity, shifts sediments, mixes water, and performs other useful work. The fish populations and the entire dynamic balance of an estuary revolve around and are strongly dependent upon circulation. Channel dredging and filling alter the flow patterns of estuaries as does the construction of bridges, causeways and piers which impede circulation.

Light

Sunlight is the basic force driving the ecosystem. It is the fundamental source of energy for plants which in turn supply the basic food chain which supports all fish. Sunlight must be able to penetrate the water so as to foster growth of the plants.

Estuarine waters are normally more cloudy (turbid) than ocean waters, being more laden with silt and richer in nutrients and phytoplankton. Excess turbidity reduces penetration of sunlight into water and thus depresses plant growth. This may be caused by excavation in water basins, by the discharge of eroded soil with runoff, by nutrients in the runoff or by sewage or industrial waste discharges which stimulate the growth of algae and lead to clouding of the water.

Nutrients

In addition to light, nutrients must be present to support the food chain. The amount of nitrate dissolved in the water is generally believed to be the primary nutrient control on abundance of estuarine plants. Nutrients continuously trickle out of the estuarine system and must be replaced by minerals in the inflow of land runoff. This supply should not be diminished.

Conversely, the ecosystem may be unbalanced by an excessive and unnatural supply of nutrient chemicals from septic tank leaching, discharge of sewage effluent, industrial organic wastes, contaminated land runoff water, and so forth. The result is overfertilization (eutrophication) which involves rapid "blooms" of phytoplankton followed by mass death and decay, clouding the water, fouling estuarine bottoms and depleting oxygen.

While sewage has been the usual suspect for overfertilization of natural waters, the potential damage by fertilizer runoff has increased dramatically—the amount of nitrogen used in agriculture in the United States increased fourteenfold in 25 years.[16] Fertilizer runoff can jeopardize the carrying capacity of estuarine systems, particularly poorly flushed ones.[4]

Water Suitability

Protection of water quality for fish life involves more than just avoiding lethal concentrations of pollutants—the water must be suitable beyond bare survival. There are definite limits below which animals desert an area or survive in very reduced abundance. Sensitive oceanic migratory fishes may be particularly affected by water suitability and abandon coastal areas with bad water. The result may be failure of a fishing area and decrease of the overall carrying capacity for the excluded species.

A variety of substances from industrial discharges or sewage effluent—heavy metals, oil, organic substances—are repelling to fish; for example, salmon avoid water with copper in very small amounts (0.0024 mg/l)[17] such as comes from fertilizer runoff.[14] Such repellents are probably responsible for the general avoidance or apparent virtual abandonment by oceanic sportfish species of many estuarine and nearshore ocean waters such as Boston Harbor, the Savannah River, and the Hudson Estuary. Elimination of all significant discharge of pollutants would restore the abundance of fishes in many of these areas.

Toxic Substances

It is not possible to determine the amount of damage done to sport fishing resources by the discharge of toxic chemicals into estuaries, but the damage appears to have been extensive; e.g., the severe reduction of the sea trout previously discussed. In another circumstantial example, the virtual disappearance of the California sardine (an important forage for pelagic game fish) is correlated with increasing DDT use after World War II (Figure 3).[18] DDT use is banned in California but a 50-square mile area off the Los Angeles sewer plant discharge (Palos Verdes area) has a persisting deposit of about 200 tons of DDT in the surface sediments on the bottom of the continental shelf.[19]

The same area has also received toxic metals from

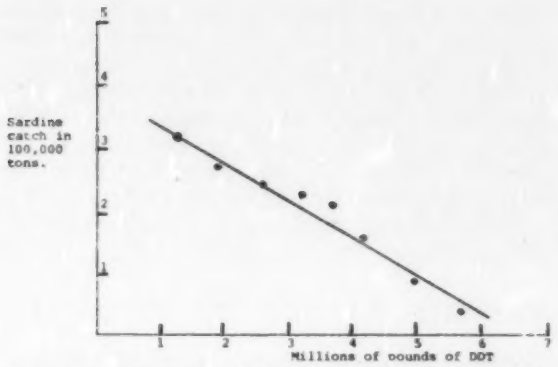

FIGURE 3.—The decline of the Pacific sardine from the mid-40's to the early 50's and the amount of DDT used in California in the same period.[18]

the discharge, leading to fish diseases[19] and widespread reproductive failure of marine species of the area. But now there are signs of a comeback as young stages of species missing for decades are reappearing in the area indicating a water quality improvement.[20] Because of the ocean outfall, water quality of the harbors is better in certain respects than that of the ocean, a reversal of the usual situation.

The NPDES program of EPA has an important role to play in eliminating the discharge of toxic substances to estuarine and coastal waters. The potential benefits are supported by encouraging results of pollution abatement efforts to date.

Severe disease (fin rot) of estuarine and coastal fishes is caused by municipal waste discharge. In the New York harbor area 22 species were affected by fin rot, including both pelagic fishes (e.g., bluefish, striped bass) and bottom fishes (e.g., flounder, hake).[20] In the Los Angeles area about 50 percent of sole, rockfish, croaker, and other bottom fish sampled were affected.[19]

Vital Habitat Area

Vital habitat areas are particularly critical elements of the ecosystem whose protection is essential to prevent degradation of the system, including depletion of fish. In the profile of the shorescape, wetlands are the areas above the mean high tide mark and below the yearly high storm mark. Wetlands, vegetated with a combination of salt-tolerant, wet-soil, plants—grasses and rushes—often grade into some combination of fresh water marsh plants at the upland edge. Vegetated tidelands are the swamps and marshes from mean high tide down to the low water mark.

Wetlands and tidelands vegetation converts nutrients in land runoff and estuarine waters to basic food for aquatic life, a sort of floating humus of small particles (detritus). It also removes excess nutrient, sediment, and other dissolved and suspended matter. The marsh and swamp areas provide critical habitats for many species as well as stabilize shorelines, prevent erosion, and buffer the force of storms and floods.

If the wetlands-tidelands vegetation is eliminated, carrying capacity of the ecosystem for fish is reduced—about 50 percent in a typical case.[22] Reduction of freshwater inflow to tidelands or canalizing or bulk-heading tidelands may also significantly reduce estuarine fish resources. Therefore, fishery management programs should require that wetlands be protected from obliteration, alteration, or degradation by pollution and by drainage or dredge-and-fill projects which reduce the area of the wetland or disrupt the natural water flow patterns—as is addressed under Section 404 of the 1972 Federal Water Act Amendments.

Submerged grass beds convert and provide detrital nutrient to the system, add oxygen (during daylight), and stabilize bottom sediments. They usually attract an abundance and diversity of life and are nursery areas for young fishes and crustaceans. Grass beds are vulnerable to turbidity, which screens out light and prevents growth of the grass, and to fine sediments (mud) which create unstable bottom conditions wherein the grasses often cannot anchor. Heated power plant effluent (along with induced turbidity) may destroy local grass beds; for example, in the Patuxent River, Md., and Southern Biscayne Bay, Fla.[13] Boat traffic over grass flats may compound the problem by stirring up sediments and ripping out plants.[4]

MANAGEMENT NEEDS

Fishing success depends upon the abundance of fish which in turn depends upon the current carrying capacity of the aquatic ecosystem. Carrying capacity itself is governed by specific limiting factors. These limits in turn are depressed by adverse ecologic impacts from development and human occupancy. Therefore, coastal sport fisheries management should incorporate ecosystem management aimed at optimizing carrying capacity.[14]

Secondly, it should be directed toward optimizing the social benefits from the resource. This requires that goals and policies for management be based upon a realistic evaluation of social, economic, and ecologic factors.

It is customary for states to regulate coastal fish-

eries. Stronger roles for both federal and local governments should be considered if successful integrated programs of fisheries management are to be implemented. Local governments sometimes regulate shellfish and less often, a herring run or other special situation. But local government plays an important role in controlling access to fishing, via roads, parking lots, beaches, piers, boat ramps.

The states have the leading role partly because fish migrate between local fishing areas. A species may spawn in one area, feed in another, and winter somewhere else again, making it impossible for any local government to act effectively. In addition, the water moves from one locality to another bringing one town's wastes to another's shores. Therefore, the states are better equipped to deal with management of fisheries.

There is clearly a Federal role for management of coastal migratory fish and for protection of interstate environments. No state can do the whole job alone because both fish and water move from state to state. For the most part interstate commissions have proved ineffective in coordinating fishery management of the states into successfully integrated programs.

Typical state fisheries management programs have dealt only marginally with the coastal environment. Fish regulations are usually aimed at allocating fish to fishermen by limiting the type of gear, size of fish, time of year, number of fish taken per day, and so forth. This passive portioning out of the catch is usually done without any attempt to scientifically optimize the yield from the ecosystems involved.

In state management the target usually is a single species. Rules are laid down for the species without regard for other species that share the ecosystem—species that may be prey, predator, competitor, or cooperator. The rules are applied through the political process in state legislatures or by appointed state commissions, under heavy lobbying pressure from fishing organizations. Opinions of state fishery biologists may be ignored because their case has not had the funds or manpower to be developed with scientific certainty. Most states have no salt water sportfish license to provide an internal source of funds for management or research on sport fishing problems. State commissioners and the general constituency of the fishery agency want to see money spent for visible structures—boat ramps, artificial reefs, and so forth—rather than advance planning, research, or administration. Consequently, the agencies are under-financed and short handed.

As a result, coast sport fisheries management is typically a series of ad hoc responses to immediate situations. In only a few states, such as California, Florida, and Massachusetts, is there any continuing management research program to serve as the basis for longer-term strategies that include environmental protection. If there is to be an effective strategy for comprehensive coastal fisheries management, there must be clearly defined long-term goals. The goals must be translated into policies consistent with social needs as determined through the political process.

The following planning framework suggests major elements that need to be considered:

1. *Resource optimization:* Devise a system of estuarine resource management that involves both harvest control and ecosystem management. Harvest control includes: bag limits, size limits, gear restriction, access limits, and closed areas and seasons. Ecosystem management includes: control of chemical and industrial pollution, protection of vital habitat areas, control of land clearing and site preparation in shorelands, maintenance of freshwater inflow, control of dredging and filling, and control of boat traffic.

2. *Access:* Provide a system of access that will guarantee an optimum pattern of fishing activity consistent with economic, sociologic, and ecologic constraints. Physical development should incorporate roadways and public transportation as well as beaches, bridges, piers, marinas, ramps, and charter boats. Social factors to be balanced should include: geographic distribution, income level, race, and availability of alternative recreation opportunity.

3. *Allocation:* Plan for a balanced pattern of allocation of fish resources including: (1) competing user groups such as commercial anglers, skin diving, and foreign fishermen; (2) the various demographic elements (see 2); (3) preferred sizes of the catch; and (4) preferred times and areas of fishing.

4. *Monitoring*: Design a system for measuring catch and monitoring user satisfaction to guide the management program.

5. *Revenue*: Examine the recreational fishery (along with commercial) to determine the revenues gained for different patterns of use and for different levels of production.

6. *Institutional*: Determine the optimum mix of federal, state and local jurisdictions, and the best methods of implementation of management actions through existing and new legislation.

It appears that this is an appropriate time for each coastal state to review its situation, to examine federal-state-local jurisdictions, to decide upon a unified set of goals, and to establish a clear set of policies for use and protection of coastal fishery resources.

The Federal government would need to participate in this process where migratory fishes and interstate environments are involved, and to provide a mechanism for coordinating activities of all federal agencies dealing with the coastal environment and coastal resources. There is now no federal policy or program on migratory fish resources. Such a role must be suitably defined by Congress through legislation, funding, and study.

The new federally sponsored Coastal Zone Management program would seem a logical framework for such a cooperative planning study, providing that sufficient importance and funds are given to the individual states to conduct comprehensive plans for land and water resource management. It is clear that only through this kind of comprehensive planning can recreational fishery resources be properly maintained and equitably shared among all Americans.

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LIMITING FACTORS AFFECTING COMMERCIAL FISHERIES IN THE MIDDLE ATLANTIC ESTUARINE AREA

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ABSTRACT

Landings of fish and shellfish by domestic commercial fishermen in the Middle Atlantic Estuarine Area (Rhode Island–Virginia inclusive) nearly doubled in weight from 1969 to 1973, from about 586 million to more than 1,074 million pounds. The increase was not accompanied by a similar increase in fishing effort, but by distinct increases in abundance of certain coastal fishes like menhaden, weakfish, summer flounder, and bluefish. In the area north of Chesapeake Bay blue crab was more abundant than it has been for more than a decade and scup also was more plentiful. It is tempting to attribute these increases to pollution abatement, but no direct proof is available. For example, the return of blue crab to the New York Bight area may have been made possible by the decline in use of DDT. All these species are known to vary widely in abundance from natural variations in environmental factors and it is difficult to separate natural from manmade causes. The only certainly adverse effects of water pollution on abundance or catches of living marine resources are those which produce obvious and measurable effects, usually catastrophic, or which result in closure of shellfish beds. Because so many important living resources use the estuaries as spawning, nursery, or feeding grounds it is prudent to avoid additional deterioration of water quality and, where possible, to reduce dumping of wastes.

INTRODUCTION

This review of the fisheries of the Middle Atlantic Estuarine Area includes estuaries and coastal waters from Cape Cod to Cape Hatteras and out to the edge of the continental shelf. This area (Figure 1) lies between latitudes 41°20′ N. Lat. and 35°15′ N. and extends seaward to the 200m. depth contour.

The offshore boundary is approximately where the shelf meets the continental slope. Although this is not exactly the definition given in section 104 (n) (4) of Public Law 92-500, it is the only rational definition for adequate consideration of the living resources upon which the fisheries of the Middle Atlantic Bight depend. Most commercial fishery resources in the area are highly migratory, and perform extensive seasonal movements east and west as well as north and south. Thus, many living resources of the area are about equally dependent upon the inshore and the offshore estuarine environment. In winter and spring many of the major migratory living resources are concentrated in relatively deep water at the edge of the shelf, some apparently favoring the major canyons. Conditions along these outer boundaries must play an important role in determining future abundance and availability of these resources to the inshore fisheries.

The definition of the Middle Atlantic Estuarine Area adopted here is similar to the definition of the Middle Atlantic estuarine region used in the "National Estuarine Pollution Study" (Anon. 1970a), although that study did not include Chesapeake Bay, but considered it as a separate region. "The National Estuary Study" (Anon. 1970b) defined the Middle Atlantic Estuarine Zone as the estuaries, bays, and coastal waters from Cape Cod to Cape Charles, Va. Chesapeake Bay was considered separately, and the area from Cape Henry, Va. to Cape Hatteras was included with the South Atlantic Estuarine Zone. None of these arrangements is entirely satisfactory for a fishery study because basic data on domestic commercial landings are recorded by states, whereas foreign and recreational catches are recorded by broader regions. The fishery resources of Chesapeake Bay are sufficiently different from those to the north that it is best to examine them separately. Because North Carolina fishery resources are transitional between Middle and South Atlantic Estuarine Areas, the commercial fisheries of North Carolina have been omitted. Thus, the two subareas of the Middle Atlantic Estuarine Area considered in the present study are Rhode Island to Delaware inclusive, and the Chesapeake states, Maryland and Virginia.

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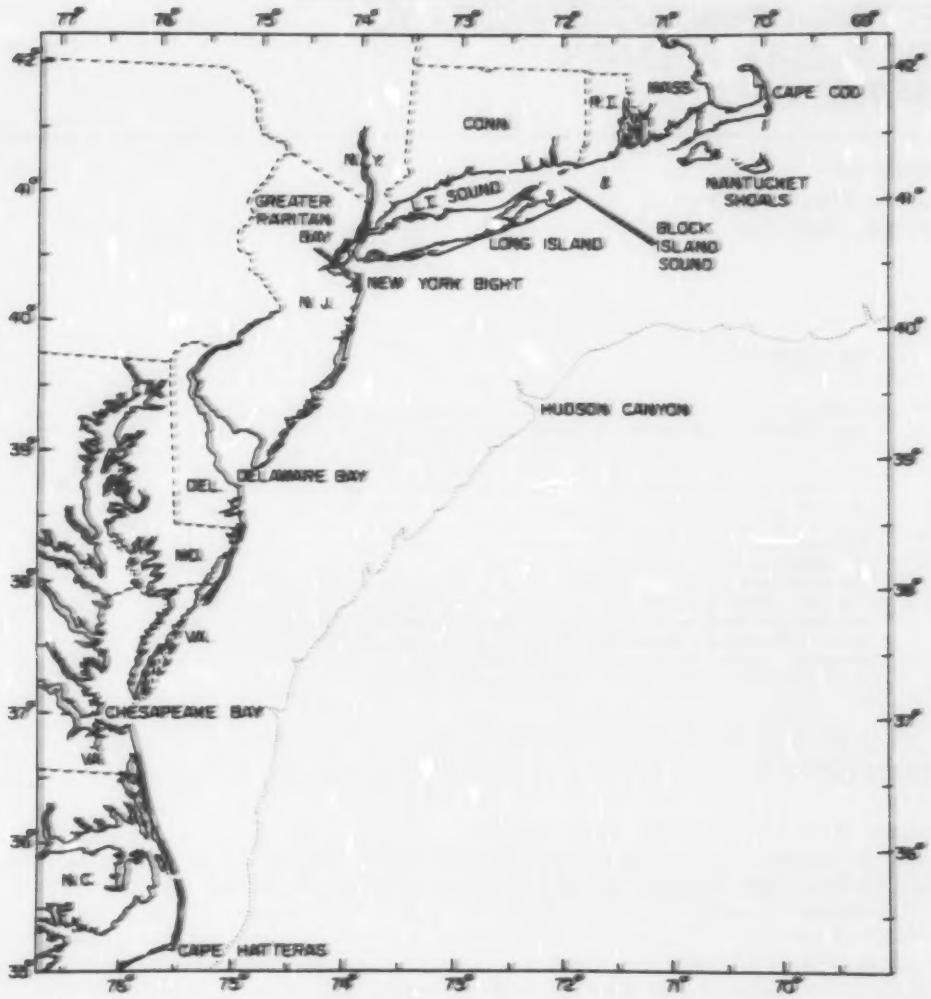

FIGURE 1.—The Middle Atlantic Estuarine Area of the United States. Not all place names mentioned in the text are included. The long narrow east-west peninsula near the southeast end of Long Island and the similar north-south peninsula at the north end of the New Jersey seacoast are Rockaway Point and Sandy Hook, respectively. A line drawn between these points separates Greater Raritan Bay from New York Bight. The Potomac River is the large river entering Chesapeake Bay from the west. The Maryland-Virginia boundary follows its southern bank. The Patuxent River lies immediately north of the Potomac and the Rappahannock River immediately south.

Within waters under national jurisdiction, from inland limits of estuarine waters to seaward limits of domestic fishery control, living marine resources are subject to many natural and manmade hazards. Subtle or catastrophic natural environmental variables can alter abundance and availability of the resources to fishermen. Various stresses created by man include not only relatively uncontrolled fishing, but also domestic and industrial wastes and engineering works which alter the environment, usually for the worse. Farther out on the continental shelf, especially at or near the edge, many of these resources remain concentrated for several months in winter and early spring. Here they are highly vulnerable to fishing, mainly by foreign fleets, but less susceptible to water pollution and other indirect human influences.

The fishery resources of the area from Cape Cod to Cape Hatteras provided a domestic commercial catch in 1973 of about 1.6 billion pounds[1], for which

[1] To convert millions of pounds to metric tons, multiply by 453.6.

American fishermen received about $119 million. The retail value of this catch could be $300 million or more. They also provided 820 million pounds to fishing fleets of at least 10 other nations. Not to be ignored is the substantial recreational catch. Surveys of saltwater sport fisheries have not been made every year, but in 1970 recreational fishermen were reported to have taken about 447 million pounds from the same community of resources, and the sport catch in the area probably was larger in 1973. The distribution of catch and fishing effort on individual stocks varies between recreational, domestic commercial, and foreign fisheries. Not included in the recreational catch are clams, bay scallop, crabs, and some other invertebrates taken in large numbers by non-commercial fishermen. The recreational catches of invertebrates have never been assessed for the area as a whole. These three segments of the fisheries of the Middle Atlantic Estuarine Area have been taking about 2.9 billion pounds of fish and shellfish annually, and perhaps more.

This essay reviews briefly the status of the commercial fisheries of the Middle Atlantic Estuarine Area in 1969, when the report pursuant to the requirements of Public Law 89-753 was completed ("National Estuarine Pollution Study"), and makes a comparison with the situation five years later, in 1974. The comparison considers what has happened in the interim, what improvements and adverse developments have been noted, what important issues need attention, what the future may bring, and what are the chances for improved management of the resource. Particular attention has been given to the effects of estuarine pollution, as directed by Public Law 92-500, section 104(n), but it has not been possible to ignore other sources of variation in condition of the commercial fishery resources. This has required, among other things, brief attention to the saltwater sport fisheries, which are properly the subject of another chapter in this volume. Assuming that other sources of attrition are, or will be, under control, continued productivity of the coastal fisheries will still depend upon appropriate control of all forms of fishing.

THE RESOURCE

Coastal fishery resources can be subdivided usefully into several categories, based not only on their value to man and to the ecosystem, but also on their geographic distributions, migratory habits, and vulnerability to manmade environmental change. One such arrangement might be:

1) *endemic resources*, like oyster, hard clam, and perhaps some migratory species of limited scope, like blue crab, white perch, tautog, and some stocks of winter flounder (category Ee in Tables 1 and 3);

2) *migratory coastal species* that do not move offshore in significant numbers beyond national fishery jurisdiction, like menhaden, croaker, and weakfish (Em);

3) *anadromous and catadromous species*, which spawn in fresh water but spend most of their lives at sea, or vice versa, like American shad, alewife, striped bass, and American eel (A);

4) *living resources of the continental shelf*, which at the harvestable stage either are immobile on or under the sea bed or are unable to move except in constant physical contact with the sea bed or the subsoil, like surf clam or rock crab (S);[2] and

5) *highly migratory resources* that move seasonally not only north and south, but also inshore-offshore between estuarine waters proper and the outer continental shelf, like red and silver hakes, summer flounder, scup, and butterfish (Om). A sixth category in this arrangement might be made up of truly oceanic species, like tunas and the great whales, which penetrate waters of the inshore estuary seldom, if at all (O).

Most of these living resources are subject to manmade stresses in the inshore estuarine environment, some throughout life, others at important stages. Assessment and control of the effects of water pollution, engineering works, and other human environmental influences, including fishing, upon the living resources is extremely difficult because at least four other major complicating forces may be operating at the same time: 1) natural variations in environmental quality, sometimes subtle, like changes in water temperature or salinity—sometimes catastrophic, like the effects of hurricane winds or heavy rains; 2) self-generated (endogenous) oscillations within individual stocks; 3) complicated and major effects of fishing operations; and 4) opinions, emotions, and political pressures generated by the effects of natural and manmade phenomena indiscriminately, which influence the regulatory process.

Status of the Resource in 1969

Judged by the total weight of fish and shellfish landed in the Middle Atlantic Estuarine Area in 1969 as compared with the past, the domestic commercial fisheries of the area had never been in worse condition. Total weight of landings was at an all-time low in recorded history, less than 37 percent of

[2] American lobster has been declared by the United States Congress a creature of the shelf, but it does not fit the definition.

the 1956 high of 1.59 billion pounds. But for most of the period up to 1956 and for some years after, industrial fish and shellfish (used for purposes other than human food) had dominated the catch, thus trends in total landings reflect principally the fortunes of the industrial fisheries, harvesting mostly menhaden for manufacture of oil and meal. When edible species are considered separately, the peak in landings came about 1930. By 1969 landings of food fish and shellfish, all species combined, in the area had been dropping fairly steadily for about 40 years.

The 1930 maximum in production of edible fish and shellfish came shortly after it was discovered that many of the resources which migrate into Middle Atlantic estuaries in spring and summer move outward to the edge of the continental shelf and southward in late fall and winter. A winter trawl fishery rapidly developed offshore to take advantage of this discovery. Major disturbances in the long-term trend since 1930 came when prices and landings dropped sharply during the economic depression of the early 1930s, rose sharply toward the end of the second world war when acute shortages of red meat at home and abroad increased the demand for protein from the sea, and fell again in the 1950s. In 1968 total weight of edible fish and shellfish landed in the Middle Atlantic Estuarine Area was lower than in any year on record except 1933, when the full force of the depression had hit the fisheries, with adverse effects on demand and prices. Total landings of edible fish and shellfish were only moderately higher in 1969 than in the low year 1968.

Table 1.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Rhode Island to Delaware inclusive). Weights in millions of pounds. Shells of molluscan shellfish not included. Species with total annual catch 50,000 pounds or less not included. Symbols: Es = estuarine endemic; Em = estuarine migratory; A = anadromous or catadromous; S = creatures of the continental shelf; Om = oceanic migratory, usually moving between international and territorial waters; O = truly oceanic

Species		1969	1970	1971	1972	1973	1972–73 as % of 1969–70
Menhaden	Em	43.8	40.6	80.4	158.3	172.5	382
Surf clam	S	42.2	52.6	40.3	32.7	31.6	68
Yellowtail flounder	Om	13.5	15.4	20.8	28.0	25.1	184
Hard clam	Es	11.4	11.9	12.5	12.1	10.2	96
Silver hake	Om	8.9	8.0	8.2	10..	11.5	133
American lobster	Om	8.0	9.3	9.0	6.3	5.4	68
Scup	Om	7.4	7.4	6.2	7.4	9.4	114
Winter flounder	Om	7.2	8.1	8.1	6.6	6.6	86
Butterfish	Om	3.6	2.2	2.7	1.2	3.0	72
Atlantic cod	Om	3.4	3.8	3.1	2.7	3.4	85
Squids	Om	2.3	1.4	1.3	1.9	2.8	127
Summer flounder	Om	2.2	3.2	3.2	3.2	5.6	170
Bluefish	Om	2.6	3.1	2.5	2.2	2.7	98
Weakfish	Om	2.0	2.4	4.8	5.6	4.3	225
Striped bass	A	1.9	1.7	1.6	1.7	3.6	147
Atlantic mackerel	Om	1.4	2.3	1.7	2.8	2.8	151
American oyster	Es	1.4	1.5	2.1	3.4	3.3	231
Red hake	Om	1.2	1.6	1.3	1.6	1.9	125
Blue crab	Em	1.1	1.2	2.2	4.0	5.0	381
Sea scallop	Om	0.9	0.7	0.5	0.5	0.6	69
Conch	Es	0.6	0.5	0.5	0.5	0.4	82
American shad	A	0.5	0.5	0.5	0.6	0.5	110
American eel	A	0.5	0.5	0.4	0.5	0.6	110
Black sea bass	Om	0.5	0.4	0.4	0.6	0.9	167
Tilefish	O	0.1	0.1	0.1	0.3	0.8	550
Bluefin tuna	Om	0.1	3.1	2.0	2.2	1.3	109
Sea mussels	Es	0.2	0.2	0.3	0.5	0.7	300
Subtotals		168.3	183.7	216.7	298.3	318.5	175
Grand totals		231.9	224.2	253.5	326.0	379.7	155

RHODE ISLAND–DELAWARE SUBAREA

Major species by weight in 1969 landings in this subarea are listed in Table 1. Surf clam dominated the edible catch, accounting for 35.6 percent by weight of all food fish and shellfish. Next in order were yellowtail flounder, hard clam, American lobster, scup, and winter flounder. Together, these six species made up nearly 82 percent of the total weight of edible fish and shellfish.

By landed value (Table 2) hard clam dominated the edible catch (nearly 29 percent of the total), followed in decreasing total landed value by lobster, surf clam, and oyster. The first four species by landed value were shellfish, and they made up 68 percent of the total landed value including industrial species. Major edible finfish species by landed value were scup, yellowtail flounder, summer and winter flounders, striped bass, and butterfish. The 10 leading species by landed value, including shellfish and industrial species, produced a gross income to domestic commercial fishermen of over $30 million, nearly 86 percent of the landed value of the entire domestic commercial catch from this subarea in 1969. This probably represents a retail value of $100 million or more.

Although landings in Rhode Island to Delaware in 1969 were almost the lowest on record, they might have been even lower if commercial fishermen had not constantly shifted to new resources as the supply of traditional resources declined. Outstanding examples of such declines were menhaden landings, which fell from a maximum of over one billion pounds in 1956 to a 1966 low of only 22 million pounds. By 1969 the menhaden catch in the subarea had increased to about 46 million pounds. The American oyster, which was reported to have produced a maximum of about 60 million pounds of meats in the early part of the 20th century dropped from about 35 million pounds in 1929 to a low of one million in 1965, and in 1969 had recovered only slightly to about 1.4 million pounds of meats. Scup was the dominant food finfish for almost two decades, reach-

Table 2.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Rhode Island to Delaware inclusive). Landed values (price paid to fishermen) in millions of dollars, not adjusted to standard dollars. * = $50,000 or less

Species	1969	1970	1971	1972	1973
Hard clam	10.3	11.5	13.5	16.0	13.9
American lobster	7.4	9.5	10.2	8.7	8.5
Surf clam	5.0	6.1	5.4	4.2	3.9
American oyster	1.5	2.0	2.8	4.4	5.1
Scup	1.5	1.8	1.7	1.7	2.7
Yellowtail flounder	1.4	1.7	2.1	3.7	4.4
Sea scallop	1.0	0.9	0.8	1.0	1.1
Menhaden	0.8	0.7	0.3	2.5	4.3
Summer flounder	0.8	1.2	1.2	1.3	2.3
Silver hake	0.7	0.8	0.7	0.9	1.4
Winter flounder	0.7	0.9	1.0	1.1	1.2
Striped bass	0.5	0.4	0.5	0.6	1.2
Butterfish	0.5	0.4	0.5	0.3	0.7
Bay scallop	0.4	0.5	0.3	0.2	0.5
Atlantic cod	0.3	0.4	0.4	0.5	0.6
Bluefish	0.3	0.3	0.3	0.3	0.3
Squids	0.2	0.2	0.2	0.3	0.6
Black sea bass	0.2	0.2	0.2	0.2	0.4
Blue crab	0.1	0.2	0.4	1.0	1.3
Weakfish	0.1	0.2	0.5	0.7	0.7
Conch	0.1	0.1	0.1	0.1	0.2
Soft clam	0.1	0.1	0.1	0.2	0.2
American eel	0.1	0.1	0.1	0.1	0.1
Atlantic mackerel	0.1	0.1	0.1	0.2	0.2
American shad	0.1	0.1	0.1	0.1	0.1
Red hake	0.1	0.1	0.1	0.1	0.1
White perch	*	0.1	*	0.1	0.1
Subtotals	34.3	40.6	43.6	50.4	56.1
Grand totals	35.6	42.5	46.7	53.0	58.6

ing a maximum of over 34 million pounds in 1960 and a minimum of 6.2 million in 1971. Landings of scup in 1969 were near this minimum, at about 7.4 million pounds. Several other species, like weakfish, had produced relatively large catches earlier and had fallen to minima in or about 1969.

To balance these substantial declines commercial fishermen turned to other species, notably surf clam. This fishery was negligible prior to the mid-1940s, but began to grow in 1945 off Long Island, N.Y. Landings from waters off Long Island reached a peak quickly and the center of operations shifted to the New Jersey coast. By 1968 and 1969 landings in New Jersey had declined slightly from a peak of over 43 million pounds of meats in 1966, and the fishery had just begun to shift to beds off the Delaware and Maryland coasts. The history of this fishery has been one of heavy exploitation of known clam stocks, entry of more capital and labor, substantial reduction of the stocks, exploration for unexploited segments of the resource, and a constant shifting toward the south. The surf clam industry provides an excellent case history of what happens to a living resource when harvesting is essentially unregulated.

CHESAPEAKE SUBAREA

Total domestic commercial landings in the Chesapeake Bay states in 1969 were lower than they had been since 1953. As in the area to the north, industrial fisheries have dominated the catch, but the 1969 catch was not an all-time low, as it was from Delaware to Rhode Island. The smallest reported total weight of landings in the Chesapeake subarea was in 1942, at just over 200 million pounds, and the trend has been upward ever since.

Landings of edible fish and shellfish in the Chesapeake area reached a peak by weight in 1930, as they did farther north, then declined, but reached even higher levels in the middle 1940s, with a maximum of about 205 million pounds. An unusual abundance of croaker and weakfish, coupled with high demand for food fish during the war and immediately after, were largely responsible for this second peak. Blue crab, alewife, and oyster dominated the edible catch in the Chesapeake subarea in 1969, accounting for about 67 percent by weight of all edible fishery products. Next in order by weight were soft clam, striped bass, surf clam, northern puffer, American shad, scup, hard clam, and white perch (Table 3).

Together, these 11 major species made up over 90 percent of total edible landings. By landed value (Table 4) the first five species were shellfish, accounting for nearly 83 percent of all edible species by value.

A steady shift from one resource to another, already noted in landings in the Rhode Island–Delaware subarea, was characteristic of the Chesapeake subarea also. Catches of the following species declined substantially prior to 1969: Atlantic croaker, down from a maximum of 57.7 million pounds in 1945 to a low of about six thousand pounds in 1968; scup down from a peak of 13.5 million pounds in 1960 to about 2.5 million in 1968; sea bass from a maximum of 10.1 million pounds in 1952 to about 1.9 million in 1969; weakfish from a 1945 peak of 24.7 million pounds to a low of 0.7 million in 1967; and American oyster from over 100 million pounds of meats before the turn of the century to a record low of 18.3 million in 1963. Countervailing upward trends occurred in landings of other species: menhaden from a low of about 64 million pounds in 1942 to record highs in the late 1950s and early 1960s, then a decline to about 180 million in 1969; striped bass, an upward trend since 1934, when the catch was only 0.6 million pounds, to a maximum of 7.8 million in 1969; blue crab from a low of 30.2 million pounds in 1942 to a high of 94 million in 1966; and soft clam from insignificant catches prior to the second world war to a peak of over 8 million pounds of meats in 1964.

Table 3.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Chesapeake Bay). Details as in Table 1. * = 50,000 pounds or less

Species		1969	1970	1971	1972	1973	1972–73 as % of 1969–70
Menhaden	Em	181.6	449.8	400.1	555.6	503.9	168
Blue crab	Em	60.9	69.8	76.1	74.5	56.1	100
Alewife	A	33.9	21.1	13.1	12.1	11.3	43
American oyster	Ee	22.2	24.7	25.6	24.1	23.9	102
Soft clam	Ee	7.9	6.2	6.0	1.9	0.6	18
Striped bass	A	7.8	5.8	4.0	5.8	7.4	97
Surf clam	S	7.3	14.6	12.3	30.7	50.8	372
Northern puffer	Ee	4.6	1.5	0.6	0.1	*	3
American shad	A	3.5	5.1	2.5	3.0	3.0	70
Scup	Om	2.9	2.1	1.9	1.3	0.8	42
Hard clam	Ee	2.7	1.8	2.2	1.5	1.4	64
White perch	Ee	2.7	1.9	2.0	1.4	1.0	52
Black sea bass	Om	1.9	1.7	0.8	1.0	1.5	69
Summer flounder	Om	1.7	2.5	2.0	2.1	3.7	138
Catfish and bullheads	Ee	1.6	1.3	1.8	1.9	1.5	117
Sea scallop	O	1.4	0.7	0.5	1.0	0.8	86
Spot	Ee	1.1	6.4	0.5	3.0	2.6	75
American eel	A	1.1	1.5	1.5	0.7	0.4	42
Butterfish	Om	1.1	1.6	0.7	0.3	0.2	19
Weakfish	Om	1.0	2.5	2.7	2.9	5.6	243
Winter flounder	Om	0.5	0.1	0.1	*	*	17
Squids	Om	0.4	0.4	0.4	0.3	0.2	62
Bluefish	Om	0.3	0.7	0.8	1.3	3.1	440
Conch	Ee	0.3	0.4	0.1	0.3	0.4	100
Carp	Ee	0.3	0.2	0.2	0.2	0.2	80
Atlantic mackerel	O	0.3	0.3	0.1	0.1	*	25
American lobster	Om	0.2	0.2	0.3	0.9	0.2	275
Sharks	Om	0.2	0.1	0.1	0.1	0.1	67
Atlantic croaker	Om	0.1	0.1	0.3	0.5	1.4	950
Spanish mackerel	Om	0.1	0.2	0.1	*	*	33
Black drum	Em	0.1	0.1	0.1	*	*	50
Yellow perch	Ee	0.1	0.1	0.1	0.1	*	75
Silver hake	Om	0.1	0.1	0.1	*	*	50
Hickory shad	A	0.1	0.1	*	0.1	0.1	100
Atlantic herring	Om	0.1	*	2.5	0.7	0.4	.....
Sea robins	Om	0.1	*	0	0	*	.....
King whiting	Om	*	0.1	*	*	*	.....
Spotted sea trout	Om	*	0.1	*	*	*	.....
Harvestfish	Om	*	*	0.1	0.1	0.2	.....
Gizzard shad	Ee	*	*	0.1	0.1	0.1	.....
Subtotals		351.1	625.9	562.4	728.7	682.9	145
Grand totals		354.1	630.4	578.4	735.1	694.6	145

Table 4.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Chesapeake Bay). Landed values (price paid to fishermen in millions of dollars, not adjusted to standard dollars). * = $50,000 or less

Species	1969	1970	1971	1972	1973
American oyster	14.0	15.1	16.0	15.2	15.9
Blue crab	7.0	5.5	7.2	7.4	7.7
Menhaden	2.8	7.6	6.5	9.3	20.6
Soft clam	2.8	2.4	3.0	1.0	0.5
Hard clam	1.7	1.1	1.6	1.2	1.3
Sea scallop	1.5	1.0	0.8	1.9	1.3
Striped bass	1.4	1.2	1.1	1.5	2.2
Surf clam	0.9	1.6	1.5	3.7	5.9
Alewife	0.7	0.4	0.3	0.3	0.3
Summer flounder	0.5	0.7	0.6	0.7	1.0
White perch	0.4	0.3	0.3	0.2	0.2
Scup	0.4	0.4	0.2	0.2	0.2
Black sea bass	0.3	0.4	0.2	0.2	0.4
American shad	0.3	0.4	0.3	0.3	0.3
Catfish and bullheads	0.2	0.2	0.2	0.3	0.2
American eel	0.2	0.3	0.4	0.2	0.2
Northern puffer	0.2	0.1	*	*	*
American lobster	0.1	0.2	0.2	1.1	0.2
Weakfish	0.1	0.3	0.3	0.3	0.7
Butterfish	0.1	0.2	0.1	0.1	*
Spot	*	0.6	0.1	0.3	0.4
Conch	*	0.1	*	*	0.1
Bluefish	*	0.1	0.1	0.1	0.2
Atlantic croaker	*	*	*	0.1	0.2
Subtotals	35.6	40.2	41.0	45.6	60.3
Grand totals	36.1	40.5	41.5	45.9	60.7

Status of the Resource in 1974

The record for 1973 must serve as an index of the condition of the fisheries of the Middle Atlantic Estuarine area in 1974, because complete statistics for 1974 were not available at the time of writing. Where appropriate, incomplete statistics (by months) or reports in the literature can be used to extend the analysis into 1974. In the area as a whole since 1969 total landings have almost doubled (Tables 1 and 3), from about 585 million to 1,054 million pounds. Most of this increase has come about through a substantial increase in menhaden landings, which in 1973 were three times the 1969 catch. The remainder of the increase was made up of substantial growth in catches of surf clam, yellowtail flounder, weakfish, summer flounder, oyster, bluefish, and some other species like croaker and tilefish for which the increase in pounds was relatively small but the percentage increase was large. Landings of Atlantic croaker, for example, were 14 times as large in 1973 as in 1969, and according to a recent report young croaker are exceedingly abundant in Chesapeake Bay in 1974, which suggests that catches will continue to increase. The relatively large increase in tilefish landings was caused by recent development of a specialized fishery out of New Jersey. These substantial increases were partially offset by decreased landings of other resources. Included in this group were alewife, soft clam, northern puffer, American lobster, hard clam, and a few others. No substantial increases in domestic fishing effort or techniques have occurred in the 5-year period, except perhaps for menhaden. This knowledge, and other lines of evidence, e.g. increased recreational catches and personal observations, can be taken as strongly supporting the view that there has been a real increase in abundance of some species of the estuaries and a real decrease in others. For species like alewife the decline in domestic landings was balanced by increased foreign catches.

RHODE ISLAND–DELAWARE SUBAREA

Landings in this subarea increased by about 55 percent from 1969 to 1973 (Table 1). Menhaden landings increased nearly fourfold and fairly large gains were recorded also for yellowtail flounder, blue crab, summer flounder, silver hake, weakfish, scup, oyster, and striped bass. These increases were partially offset by declines in landings of surf clam, American lobster, and a few other species. The decline in lobster catches may have been a result of decreasing fishing effort.

CHESAPEAKE SUBAREA

Domestic commercial fishery landings in this subarea almost doubled from 1969 to 1973. The major increase here was also in menhaden landings, which almost tripled in this subarea. The increase in total landings had been even greater in 1972, from about 354 million pounds in 1969 to about 735 million, more than doubling the 1969 catch. Food fish and shellfish landings were moderately higher in the Chesapeake subarea in 1973 than in 1969, largely because surf clam production rose by more than 43 million pounds of meats, almost a sevenfold increase. But this substantial increase was partially offset by a major drop in alewife catches, catastrophic declines in production of soft clam and northern puffer, and moderate drops in catches of several other species (Table 3).

PROBABLE CAUSES OF CHANGES

Most living resources of the coastal zone fluctuate widely in abundance from natural causes. Natural changes in environmental conditions at critical stages in the life history obviously affect survival and future abundance, but our understanding of cause and effect is very poor and probably always will be. When the fortunes of the fisheries are viewed against this background of natural change it is difficult to determine the relative contributions of fishing, water pollution and other manmade effects, and natural environmental variations. The effects of fishing can be measured if accurate information is available on catches and amount of fishing effort over a reasonably long period of time. But similar information on most other manmade effects, and on naturally-caused changes in abundance, is not available. Thus, conclusions about the causes of changing abundance of living resources are likely to be largely intuitive.

To assess the reasons for the changes observed between 1969 and 1973 in commercial fishery landings in the Middle Atlantic Estuarine Area it is helpful to retreat to the narrower and more commonly used definition of an estuary: a semi-enclosed coastal body of water having a free connection with the open sea and within which the sea water is measurably diluted with fresh water derived by land drainage. It is in such bodies of coastal water that effects of human activities are most pronounced. This includes Long Island and Block Island Sounds, Greater Raritan Bay (inside a line joining Rockaway Point and Sandy Hook), Delaware Bay, Chesapeake Bay, and all estuaries and bays lying inside the fringe of barrier beaches along the south shore of Long Island and the ocean coasts of New Jersey, Delaware, Maryland, and Virginia. Because it has been a major waste disposal site for many years, the apex of New York Bight is also included, although it does not fit the conventional definition.

This separation of estuarine and shelf waters eliminates some major living resources in Tables 1 to 4 from consideration insofar as strictly estuarine processes are concerned. These resources are: surf clam, yellowtail flounder, cod, haddock, Atlantic mackerel, sea scallop, tilefish, bluefin tuna, and probably a part of the lobster resource. It is assumed for the purposes of this study that these essentially oceanic species, and perhaps some others which do not reside in coastal waters close to shore for any great length of time, are not presently affected significantly in abundance by human alteration of the estuarine environment. However, it must be remembered that large oceanic fishes like tunas and billfishes have been shown to accumulate relatively large residues of heavy metals and other contaminants which may have come from estuarine sources via the food web. Changes in abundance of these species must be assumed to be caused by natural environmental changes, or by the effects of fishing, or both. This leaves about 25 species, more or less, depending upon how one defines importance to the domestic commercial and recreational fisheries, about which we should be particularly concerned with respect to the effects of manmade environmental modification. These resources have been identified by code letters in Tables 1 and 3.

Species Which Have Produced Major Changes in Landings 1969–74

Of this group of about 25, nine have shown considerable increases in landings in the area as a whole, and these increases are almost certainly associated with real increases in abundance, for reasons already given. Another eight, or perhaps nine, have shown

considerable declines in landings, some of which have been associated with real decreases in abundance. Two additional species have produced major increases in landings in the Rhode Island–Delaware subarea only, and another three have declined only in the Chesapeake subarea. Before discussing specific environmental alterations which may have been responsible it is helpful to examine briefly most of these species to find out whether it is possible to identify all or some of the reasons for the major increases and declines.

AMERICAN OYSTER

The oyster industry of the area now produces much less than it once did, but this still is the most important oystering area in the nation. In the late 1950s and early 1960s one calamity after another hit the industry, first a massive invasion of sea stars in Long Island Sound, then specific diseases of oysters in Delaware Bay and later in Virginia. It is not known whether reduced water quality was a factor in these epizootics, but it is possible that the new stresses exerted on the resource by manmade environmental changes may have made the oyster more susceptible. These outbreaks almost destroyed the industry in all major producing areas from New York to Chesapeake Bay except in Maryland. The relatively low-salinity waters of the northern part of Chesapeake Bay are particularly favorable for oyster growing, and a massive rehabilitation program, consisting mainly of replanting shell and transplanting live oysters, by the State of Maryland on public oyster grounds has more than doubled production there since the low year 1963. This has demonstrated that oyster production can be increased if governments are willing to spend the time and money to do so. Whether this has contributed any increased revenue to the local economy apparently has not been demonstrated.

In the New York and Chesapeake areas some success has been attained at raising seed oysters in hatcheries. At this stage, however, opinion is divided as to whether this is an economically sound method of resolving the problem of highly variable natural seed production. In the other Middle Atlantic states private enterprise, sometimes with help from the states, has been improving oyster production slowly. In the area as a whole landings have increased about 15 percent from 1969 to 1973. In Maryland the increase has been more than 19 percent in the 5-year period, but this and the modest gains in other states have been partially off-set by a drop in Virginia oyster production.

Much of the blame for the long-term decline in oyster production has been attributed to careless oystering practices, but water pollution also has hurt the industry by forcing closure of more and more areas for public health reasons, and by adversely affecting survival of larvae and young. But aside from setbacks by severe storms, and severe outbreaks of predation or disease, industry and government probably will be able to continue improving the volume of oyster production to satisfy existing demand.

HARD CLAM

Hard clam is harvested in all states in the Middle Atlantic Estuarine area, but New York now is by far the largest producer. Most of this production comes from Great South Bay on Long Island. From 1929 to 1957 Rhode Island and New York vied for first place in volume of hard clam landed, but since 1957 landings have been rising in New York and falling in Rhode Island. The decline in Rhode Island probably has been caused by over-harvesting, but the rise in New York landings almost certainly has represented a large increase in abundance in Great South Bay over the past 15 years. In both states the industry has been plagued by water pollution, which has led to progressive closing of productive clam beds, especially on Long Island, where the human population is growing more rapidly than in any other area of the United States. Large areas of clam bottom are closed or restricted along the New Jersey coast, as in other states of the area. Where clam digging is permitted the harvest is intense because demand is good and prices high.

Many experienced baymen believe the available resource is being overharvested. That conclusion is hard to escape with respect to the Rhode Island hard clam industry, which now produces only about 20 percent of the catch of 20 years ago. The harvest in New York reached a peak in the period 1969 to 1973 and this is reflected in the record of landings for the subregion (Table 1). Clam diggers in Great South Bay report that they now must work harder to make the same catch. Clam fisheries in the area generally are subject to a negative form of management, in which water quality is checked frequently and grounds are closed to harvesting when coliform bacteria numbers exceed minimum values. This is important, but is not likely to maintain yields of clam resources when the total catch needs to be controlled also. The towns that have jurisdiction over clam beds in Great South Bay, especially the town of Islip, are now beginning to develop model research and management programs based on improved law enforcement, better understanding of

the dynamics of the resource, and transplantation from polluted to clean areas. They deserve to be encouraged and supported adequately.

SOFT CLAM

The soft clam industry of the area developed in Maryland waters in the 1950s to supply markets that could no longer be satisfied by a declining catch in New England. The abrupt decline in landings from 1971 to 1972 and 1973 (Table 3) was caused by the effects of tropical storm Agnes, in June 1972, which brought down such a load of contaminants from land drainage after heavy rains that the State of Maryland found it necessary to prohibit harvesting in the interest of public health. Before water quality had recovered to safe levels, low salinities and high water temperatures had killed most soft clams in commercial clamming areas. Restrictions were placed on the catch in 1972 and 1973 because it was feared that the sharply-reduced resource could not withstand an intense fishery. It was expected that landings would be considerably better in 1974, and monthly statistics received to date have borne this out.

WHITE PERCH

This species also is most abundant in the Chesapeake segment of the area. Commercial landings in Chesapeake Bay have dropped to almost one-third of the 1969 level, but this may not have been a consequence of declining abundance. White perch is taken in large quantities by sport fishermen in the area, especially from New Jersey south, and the estimated recreational catch is much larger than the commercial catch. White perch is endemic to the inshore estuary, and in Maryland waters of Chesapeake Bay it is considered to be underexploited. The decline of the commercial fishery there probably has been caused by overcrowding and slow growth, which has affected prices. In Virginia, on the other hand, the species is believed to have been affected adversely by water pollution, especially in the James River.

NORTHERN PUFFER

The major fishery for puffer in the area also has been in Chesapeake Bay. Peak landings were reached in 1965, and landings have been erratic and generally downward since that time. The initial decline was caused by excessive catches in 1965, and in 1966 a considerable supply of puffer was held over in cold storage from the previous year. The species is notably variable in abundance, apparently from wide variation in success of spawning, which is especially evident in short-lived species; but, as with other species, the causes of fluctuation are not known. Commercial landings dropped from 4.6 million pounds to less than 50,000 from 1969 to 1973 (Table 3). Considerable numbers are taken by sport fishermen in the area as a whole, and the recreational catch has dropped sharply in New York and New Jersey as well as in Chesapeake Bay.

SPOT

This is a fish of estuaries and inshore coastal waters. It was once fairly important along the western end of Long Island and the New Jersey coast, but commercial catches have been relatively minor since the middle 1940s. The reason for the decline is not known. Spot is a short-lived fish, and wide variations in success of spawning are reflected in catches almost immediately. The increase of about 1.5 million pounds in the commercial catch from 1969 to 1973 probably merely reflects such variations, for the 1970 catch was much higher (Table 3).

BLUE CRAB

The blue crab fishery has been centered in Chesapeake Bay, and landings to the north have historically been much smaller. Abundance and catches have varied widely in the Chesapeake, but the long-term trend in landings has been upward since the 1930s, although the peak catch of about 97 million pounds in 1966 has not been exceeded. From Delaware north the maximum catch was 6.6 million pounds in 1950, and fluctuations have been relatively much wider north of Chesapeake Bay. The northern fishery declined after about 1957 and in New York no commercial catch has been reported since 1961. In the 1970s blue crab began to increase in abundance in bays along the south shore of Long Island, and although commercial fishing has not resumed in New York, recreational catches of blue crab are reported to have been substantial. Similar increases have occurred in New Jersey and Delaware also. The increased commercial catches in those states are shown in Table 1.

It has been speculated that recovery of the resource in New York has been caused by the ban on use of DDT and other chlorinated hydrocarbons for mosquito control. Suffolk County, New York, was reputed at one time to have the most massive spraying program in the country. Partial recovery of the

fishery in New Jersey and Delaware also might have had the same cause, but there is no proof that this was so in any state. Whatever the cause, landings by commercial and recreational fishermen north of Chesapeake Bay have certainly increased substantially, and the reported commercial catch has now recovered to about 76 percent of the all-time high. Because the recreational catch probably is much larger now, the condition of the resource probably is better than indicated by commercial landings alone.

ATLANTIC MENHADEN

The 5-year increase in landings of menhaden north of Chesapeake Bay was substantial, but 1973 landings were still far short of the maximum reached in 1956. In the Chesapeake subarea, however, menhaden landings in 1972 were the highest on record, in 1973 second highest. The 1970 Chesapeake catch was the third best year on record and 1971 the sixth. The intense fishery in the Chesapeake subarea now takes mostly 1- and 2-year-old immature fish, and allows relatively few to survive long enough to migrate farther north. The increased catch to the north may have been related to greater abundance in the south, or survival from local spawning may have been better because competition from migrating southern menhaden had been largely eliminated for a while. That the menhaden resource has been able to produce bumper crops despite the very heavy drain on the stock by commercial fishing is reasonably good circumstantial evidence that levels of water pollution in the area and other manmade environmental changes have not been great enough to affect the menhaden resource. If water pollution or other human influences have affected the resource in the past, it could be assumed that conditions have improved recently as far as menhaden is concerned. Virtually nothing is known about the environmental variables that control the size of the menhaden stock. It is difficult to understand how this resource has been able to survive such a heavy fishery, and indeed produce such large catches after it appeared that the stocks of menhaden had been seriously overfished. It has been noted by several workers that just before a fish stock collapses it may produce one or more very large year classes. No explanation has been advanced, except speculation that in some way the internal regulatory mechanisms of the stock break down. Thus, the recent large catches of menhaden in the area may be more a matter for concern than for optimism. Events in the fishery in the last five years illustrate as well as any case history of a fishery how poor is our capability to explain and predict what is happening. Among other things it also demonstrates why it is so difficult to assess the effects of a specific pollutant, or even of water pollution generally. If pollution control is able to prevent further deterioration of the estuarine environment; or even better, if estuarine pollution can be reduced; the inevitable decline of the menhaden fisheries of the area, when it comes, will most likely be caused by overfishing, abetted by the effects of natural environmental changes. A decline is assumed to be inevitable if the present high demand for the product continues, and the fishery remains essentially unregulated.

STRIPED BASS

Abundance and catches of striped bass in the area have been following an upward trend for some 40 years, although the Chesapeake catch appears to have leveled out for the past decade. This trend shows in commercial and recreational landings, and there is no good reason to doubt that abundance has increased substantially, although the evidence is circumstantial, as it is for most of the species under discussion. This upward trend may not be evident to the short-term observer, and it is not clearly evident in the period 1969 to 1973 (Tables 1 and 3), because the trend is superimposed upon a background of wide variations in spawning success which have caused large short-term fluctuations in abundance. Thus, in any period of a few years landings are about as likely to be dropping as they are to be rising.

The long-term trend in commercial landings can be recognized clearly in the progression of highs and lows. Since 1930 each major high in commercial landings in the area as a whole has been higher than the previous one, and each low also has been successively higher. It is very unlikely that this increasing commercial harvest reflects only an increase in fishing effort, for striped bass historically has been a popular food fish. Sport catches also have been trending upward, although a part of this increase must have been associated with the demonstrated increase in sport fishing effort.

It has been suggested that, because they spend the first two years of their lives in the estuaries, striped bass have been able to take advantage of the increased nutrient supply contributed by domestic wastes. This is only an hypothesis, which cannot be confirmed by existing evidence that links cause and effect. Nevertheless, it seems that striped bass has so far been able to cope successfully with human alterations of the environment, as well as with continued intensive fishing.

This is not cause for complacency, however, for it

is not known for certain why striped bass apparently has been increasing in abundance for more than a quarter-century, nor even why, along with this trend, abundance has fluctuated so widely in the short run. It explains nothing to say that such fluctuations are to be expected in resources which live in a rich but highly variable and sometimes hostile environment, although a more rational approach toward fishery management might be possible if this fact of variation were more clearly recognized. It would be a matter of concern, of course, if the magnitude of such fluctuations were to increase. Nor is it cause for complacency, even if proof were available that added nutrients had favored striped bass abundance, for the process is likely to be reversible if the nutrient supply continues to increase.

ALEWIFE

Of all species which have declined in commercial landings in the area since 1969, alewife landings have dropped most sharply. In the Middle Atlantic Estuarine Area the species is important commercially only in Chesapeake Bay. Recently, from 80 to 90 percent of the catch is landed in Virginia. Chesapeake landings of alewife dropped from about 34 million pounds in 1969 to slightly more than 11 million in 1973, largely because large quantities have been taken by foreign fleets offshore. As a consequence, the United States, by negotiating bilateral agreements with some nations, has imposed strict quotas on some catches. There is no evidence that manmade environmental changes other than fishing have affected the resource in this area, but anadromous species like alewife are especially vulnerable to estuarine water pollution.

AMERICAN SHAD

The decline in landings of shad in the area, especially north of Chesapeake Bay, does not necessarily signify a decline in abundance of the species. It is known that economic factors rather than a scarcity of fish have been the primary cause of the recent decline of the Hudson River shad fishery. Modern transportation and preservation facilities have made it easier to ship shad from early runs to southern rivers for marketing in New York at high prices. By the time shad runs begin in the Hudson River local demand has been sated because shad traditionally has been a short-term seasonal delicacy, which forces the price too low for profitable fishing. Actually, it is reported that water quality in the Hudson River has improved in most areas, and off-flavors of shad are less prevalent now. Like other anadromous species, shad always will be vulnerable to environmental deterioration. Foreign catches of shad have not been reported.

MIGRATORY COASTAL FOOD FISHES

Several once important food fishes have made encouraging recoveries in abundance in the period since 1969, although commercial landings of these species are still far below historic maximum levels. Included are scup, weakfish, bluefish, summer flounder, and Atlantic croaker. All five are important recreational species as well, and the saltwater sport fisheries have benefited particularly from this partial recovery. The magnitude of the recovery probably was greater than commercial landings suggest, because although statistics are not available on recreational catches of these species in the area except for 1970, it is demonstrated that the popularity of saltwater sport fishing has been increasing. It must be recognized that increased commercial or recreational landings do not by themselves demonstrate an increase in abundance, for increased catches may simply signify greater fishing effort or improved availability of fish to fishermen for some reason. Assumption beyond reasonable doubt that these species, and some others, have truly increased in abundance comes from personal experience, conversations with scientists and fishermen, and innumerable reports in trade magazines and sport fishermen's publications. Bluefish apparently have been particularly abundant recently, as demonstrated by large sport catches, and by unusual numbers taken by commercial and research trawlers offshore. Croaker have been appearing again off the coasts of Delaware and New Jersey, where they have been virtually absent for years. As mentioned already, recent reports suggest that croaker catches may increase dramatically in 1975 and subsequently.

Wide variations in abundance of all these species have been noted several times in the past. No one has identified the reasons for these fluctuations, and no one can predict what will happen in the future. The recent increase in weakfish abundance appears already to have been temporary, as might be expected from past experience. Weakfish appear to be scarcer in 1974. All spend important parts of their lives in the inshore estuary throughout the area, and it can be assumed that they are affected in various ways by what man does to the estuarine environment, but the extent of such effects is not known except when major kills of obvious origin occur. Two of the five, scup and summer flounder, are highly vulnerable to foreign fishing. All, however, are taken

by domestic commercial and recreational fishermen at all seasons, in various places, and by various gears. Present laws and regulations, and the means to enforce them, are totally inadequate to manage these fisheries effectively, even if the necessary scientific knowledge were available. It is theoretically possible to regulate the harvest to maintain optimum yields, but it is questionable whether the necessary public cooperation and adequate funds will be available.

SILVER HAKE

Rather surprisingly, domestic commercial landings of this species have increased since 1969 in the area. For several years the International Commission for the Northwest Atlantic Fisheries (ICNAF) has been concerned about the stocks of silver hake and has placed quotas on the catch. The species is not abundant south of New Jersey, and commercial catches from the area are determined more by the market than by the supply of raw material. The increase of about 2.5 million pounds in area landings in the 5-year period cannot be interpreted necessarily as an indication of increased abundance. Demand for silver hake as human food is limited, and the price is highly sensitive to market conditions. The incentive to fish for this species varies accordingly. However, successful spawnings in 1971 and 1972 had led to predictions of increased catches later.

AMERICAN LOBSTER

The lobster harvest south of Cape Cod has been growing for about a decade. This has been attributed to two developments, a southward shift of lobster stocks and increased abundance to the south in response to declining coastal water temperatures, and new fisheries on hitherto under-exploited lobster stocks in relatively deep water on the continental shelf. As with so many popular explanations based on observations of general environmental change, the drop in water temperature and the increase in lobster abundance were real, but the cause and effect hypothesis has not been proven. Many lobstermen think that the harvest has been too intense and that the resource has been overfished. This is quite likely, for in common with most other fisheries of the area, the states have many fishery laws and regulations, but there has been no control on the amount of fishing. Uncertainty about the catch of lobster by foreign fleets and by recreational fishermen further complicates the problem.

Others think that a reversal of the environmental trend that originally led to the growth of the fisheries south of Cape Cod is now responsible for declining catches. There is no evidence that manmade changes other than fishing have affected lobster abundance in the area. It is to be hoped that the relatively new federal-state lobster research and management program will help to answer these questions and prevent overharvesting of lobster. Whatever the cause, landings in the area by domestic commercial fishermen dropped from a reported 8.2 million to 5.6 million pounds from 1969 to 1973 (Tables 1 and 3).

WINTER FLOUNDER

This coastal species does not make extensive migrations, and it tends to be subdivided into local populations which do not intermingle freely. It has a history of wide fluctuations in abundance which appear to have been caused by natural environmental changes. Winter flounder is not very abundant south of New York. The decline in commercial landings since 1969 (Table 1) has no great significance in terms of abundance of the resource.

BUTTERFISH

In the late 1960s butterfish was considered to be a very much underharvested species. Foreign fleets, especially those seeking squid, now are taking increasing quantities, and it is believed that the harvestable surplus is now being fully utilized. Under such circumstances it could be expected that domestic catches will be smaller than before, and this may explain the drop of about 1.5 million pounds in domestic commercial landings since 1969 (Tables 1 and 3). Possible effects of estuarine pollution cannot be ruled out, however.

Estuarine Pollution

Water pollution probably shares top place with uncontrolled fishing as the most serious threat to the economic well-being of the domestic commercial fisheries. The sessile endemic resources, like oyster, clams, and mussels, are particularly vulnerable because, once the free-swimming larvae have settled to the bottom, these resources are non-migratory. For practical purposes conch also falls in this category. Other estuarine endemic species can to some extent avoid gross pollution unless they become trapped for some reason. Little is known about sublethal effects, although there is evidence that they can be serious.

The most obvious damaging effects of estuarine pollution to living resources and to commercial and

recreational fishing are the threats to human health caused by intake and retention of human pathogens by molluscan shellfish. The principal reason is that shellfish such as oyster and hard clam frequently are eaten raw. Many formerly productive shellfish grounds in Rhode Island, along the Connecticut shoreline, around the coast of Long Island, along ocean coasts from New Jersey to Virginia inclusive, and in Raritan, Delaware and Chesapeake Bays, are now closed to shellfishing, or are open only under special permit to take shellfish for further processing. The areas so restricted include substantial parts of coastal waters of the seven states in the Middle Atlantic Estuarine Area, and the total area closed is still increasing. The State of New York controls about 425,000 acres of shellfish bottom, of which about 100,000 acres are closed because water quality does not meet minimum standards. Thirteen percent of these waters were closed in 1973. This not only progressively reduces the area of bottom approved for shellfish harvesting and therefore the potential yield, but also increases the likelihood that consumption of shellfish taken illegally will cause outbreaks of hepatitis or other human disease. Such outbreaks not only are dangerous to public health, but also can have disastrous immediate and long-term effects on the economy of the industry through erosion of consumer confidence. Oysters and clams to be eaten raw bring the highest prices, so are harvested selectively. Thus, the economic threat to the industry is ever-present and very great. In the period 1969 to 1973 molluscan shellfisheries of the inshore estuaries of the Middle Atlantic Estuarine Area produced a harvest for which fishermen received more than $35 million a year, on the average, which was more than 38 percent of the landed value of all fish and shellfish caught commercially in the area.

In addition to these non-migratory resources, several other species remain within the inshore estuaries throughout their lives, and thus may be more vulnerable to water pollution than the highly migratory species which come and go. Blue crab is the most important of these, especially in Chesapeake Bay, where it is the most important edible species by weight and second most important in landed value. Among the highly migratory species, the anadromous fishes are especially vulnerable because the young are born in those parts of the estuaries most susceptible to pollution. Included are such valuable species as striped bass, alewife, and shad. Sublethal effects in the natural environment are extremely difficult to detect and their influence on the living resources difficult to evaluate. Thus, it should not be assumed that such effects are insignificant.

Mass mortalities of menhaden and other species sometimes occur in estuaries. Such mortalities in Chesapeake Bay often have been associated with a natural deficiency in dissolved oxygen content of the water in the central part of the bay and in the lower parts of the major rivers in that area, especially the Rappahannock, Potomac, and Patuxent. Domestic and industrial waste disposal has aggravated this natural condition by creating an additional oxygen demand. A similar condition, which has become more serious as the human population has grown, exists in summer in the western part of Long Island Sound. Interpretation of the effects of these man-made changes is very difficult for at least two reasons, both of which have been demonstrated dramatically in Chesapeake Bay in the 1969-1973 period. Hurricane Agnes in 1972 caused heavy mortality of molluscs, partly, but not entirely, from intensification of natural conditions. Unusually great abundance of certain species, such as menhaden, will per se increase the numbers of fish killed, and perhaps the frequency of kills, even if the environment has not changed. These interactions of natural and man-made forces make it extremely difficult to measure cause and effect, because we do not know specifically how these factors operate individually, or how they interact.

At some places in the area, e.g. in Barnegat Bay, N.J., and Long Island Sound, N.Y., waste heat from power plants has had beneficial effects on sport fishing. Species such as bluefish, striped bass, white perch, menhaden, and others become entrained in the warm plume of discharged cooling water and support recreational fisheries in winter where none existed before. Plant shutdowns or sudden weather changes sometimes cause sudden mortalities. The power companies are seldom praised for such fortuitous creation of new sport fisheries, but they are immediately vilified when a kill occurs. It seems unlikely that such kills can have significant permanent or even immediate effects on the resources involved, although local effects can be catastrophic.

In summary, the only certainly identifiable effects in the natural environment of estuarine water pollution on the living resources and their fisheries are: 1) transfer of human pathogens; 2) closure or restriction of harvesting on molluscan shellfish beds; and 3) catastrophic releases of pollutants in which cause and effect are obvious.

It follows that we have no positive explanation why many important species in the Middle Atlantic Estuarine Area have increased substantially in abundance in the period 1969–1973, and thus cannot attribute these recoveries to pollution abatement,

where abatement has occurred. However, many laboratory studies and some controlled field studies have shown that all species studied are affected adversely by many components of water pollution. This is sufficient to support the conclusion that many pollutants are deleterious to fishery resources and to human health.

Domestic Management of the Fisheries

A primary objective of fishery management is to maintain the resource in a condition to produce the optimum sustainable yield, which means economic as well as biological health. Despite the short-term increase in landings from 1969 to 1973, which apparently was not the result of an equivalent increase in fishing effort, it is fairly obvious from the long-term record that we have not achieved effective fishery management in the Middle Atlantic Estuarine Area. The declining total catch of food fish and shellfish, despite constant and progressive shifting from resource to resource, is sufficient evidence of that. There has been no dearth of opinion as to what is wrong with the fisheries of the area and what are the remedies. Many of these views have been translated into laws, and all of the states have voluminous codes of fishery statutes, few of which have any basis in fact.

The only exceptions in the seven-state area are the oyster and soft clam management programs of the State of Maryland, already mentioned. These have more than doubled oyster production in that state in 10 years, 25 percent of which increase occurred from 1969 to 1973 (masked in Table 3 by a concurrent drop in Virginia); and are bringing about recovery of the soft clam resource and fishery. In New York State the town of Islip, which controls about one-third of the bottom of Great South Bay, has embarked on a promising program to manage the hard clam resource. If successful, these programs will be models for other local communities and states to follow. The difficulties should not be underestimated, however. Not the least of these is the extreme difficulty and cost of law enforcement associated with resources in shallow water, near shore, and easily accessible to the public generally. Without adequate enforcement, the best program in the world will fail.

Foreign Fishing

Fishing by other nations on the continental shelves surrounding the United States has become the major concern of domestic fishermen. It has overshadowed all the other problems of the coastal fisheries of the nation and of the Middle Atlantic Estuarine Area. This dominance of foreign fishing over all other fishery problems probably occurred because it presented an obvious "villain" which could be blamed, rightly or wrongly, for most of the ills of the domestic commercial and recreational fisheries. This scapegoat has no means of fighting back at the domestic level. Foreign fishing has seriously affected some traditional American fisheries, such as Georges Bank haddock and Pacific halibut, to name only two. Foreign fishing as a serious problem for the domestic fisheries of the area began in 1965 and 1966, when the Soviet Union took a large harvest from the strong 1963 year class of haddock on Georges Bank, and then began to extend its operations to the south and west. As early as 1963, however, the USSR did some fishing south of Georges Bank. Now at least 10 nations besides the United States are fishing in the Middle Atlantic Bight.

Of some 47 major species in the domestic commercial and recreational fisheries of the Middle Atlantic Estuarine Area, 18 are also being taken by foreign fleets on or over the continental shelf. The other 29 domestic species either do not enter the high seas beyond the 12-mile zone of national fishery jurisdiction or do so in such small numbers or for so short a time that incidental catches by foreign fishermen would not be a serious problem. The only exceptions are menhaden, which sometimes are found beyond 12 miles in substantial numbers, especially off Virginia and North Carolina in winter, and surf clam, which is widely distributed on the continental shelf in the area. It does not seem likely that specialized foreign fisheries for these species will develop. The surf clam has been declared a creature of the continental shelf under the provisions of the 1958 Geneva Convention, which thus reserves this resource to the United States.

Table 5 shows reported landings of the 18 species or groups of species fished jointly by domestic and foreign fleets in the area. The foreign catches are probably higher than they should be for direct comparison, because they include Georges Bank. Virtually none of the domestic landings listed comes from Georges Bank.

Some of the species migrate between waters over Georges Bank and the Middle Atlantic Estuarine Area (e.g. Atlantic herring and mackerel), others, such as winter flounder, probably do not. The alewife resources of Chesapeake Bay definitely have been affected by the foreign fisheries, as the decline in domestic landings illustrates. Foreign catches of scup have been relatively small, but even these small catches are of concern because the scup resource has

Table 5.—Domestic (upper row) and foreign (lower row—ICNAF subareas 5z and 6) commercial catches of major species taken by both groups in Middle Atlantic Estuarine Area 1966-73. Weights in millions of pounds. * = 50,000 pounds or less. — = no catch reported

Species	1966	1967	1968	1969	1970	1971	1972	1973
Alewife	34.4	30.7	36.5	33.9	21.1	13.1	12.1	11.3
	—	14.3	49.1	79.8	43.6	47.8	27.5	14.0
Scup	25.9	18.6	13.9	10.3	9.5	8.1	8.7	10.2
	2.0	1.8	5.1	1.1	0.4	2.2	3.7	3.9
Summer flounder	9.8	8.1	6.3	3.9	5.7	5.2	5.3	9.3
	—	—	—	—	*	1.5	0.9	*
Yellowtail flounder	9.5	11.4	12.3	13.5	15.4	20.8	28.0	25.1
	0.2	0.2	0.2	42.1	6.8	4.6	12.1	1.4
Silver hake	9.2	11.0	9.7	9.0	8.1	8.3	10.9	11.5
	472.4	195.4	132.0	166.4	72.6	182.0	233.0	254.7
Winter flounder	9.2	9.0	7.6	7.7	8.2	8.2	6.6	6.6
	0.2	0.2	0.2	15.0	1.1	3.7	5.5	3.4
Atlantic herring	7.4	1.7	0.8	0.1	*	2.5	0.7	0.4
	305.1	479.5	822.1	674.4	540.8	570.3	377.8	435.9
Butterfish	5.4	4.9	3.4	4.7	3.8	3.4	1.5	3.2
	8.6	5.1	11.9	33.0	19.8	13.9	12.3	39.3
American lobster	4.9	4.8	6.5	8.2	9.5	9.3	7.2	5.6
	—	—	—	—	—	0.2	0.4	0.5
Black sea bass	3.2	2.5	2.4	2.4	2.1	1.2	1.6	2.4
	—	—	—	—	—	—	—	—
Squids	2.6	2.9	3.0	2.7	1.8	1.7	2.2	3.0
	*	*	3.7	15.6	33.0	44.7	104.5	121.4
Atlantic mackerel	2.4	2.1	2.9	1.7	2.6	1.8	2.9	2.8
	15.0	41.9	123.7	239.8	450.6	517.5	843.0	836.3
Red hake	1.5	1.4	1.1	1.2	1.6	1.3	1.6	1.9
	239.4	117.5	29.3	108.5	16.1	59.3	162.4	137.7
Atlantic cod	1.2	2.2	2.9	3.4	3.8	3.1	2.7	3.4
	90.8	52.0	61.5	46.7	23.8	26.0	25.8	28.0
Sea robins	0.9	0.6	0.5	0.1	*	*	*	*
	3.1	1.1	19.8	4.2	*	1.8	8.1	6.2
Tilefish	0.9	0.1	0.1	0.1	0.1	0.1	0.3	0.8
	—	—	—	—	—	—	*	—
Sharks	0.9	0.5	0.4	0.2	0.1	0.1	0.1	0.1
	19.4	5.3	8.8	19.2	12.3	24.2	46.3	33.8
Bluefin tuna	0.5	3.2	0.2	0.1	3.1	2.0	2.2	1.3
	—	—	—	—	—	1.1	0.4	0.2

decreased sharply in abundance since the 1950s. Summer flounder catches by foreign fishermen also have been small, but foreign catches may be larger than reported because some summer flounder may have been included in unclassified catches. Relatively large foreign catches of yellowtail flounder have led to quota limits on this species by ICNAF, but the effects on the fisheries of the Middle Atlantic Estuarine Area are not evident in the record of domestic landings. Yellowtail flounder in the area probably belong to a distinct stock, and catches on Georges Bank probably would not affect this stock. Although landings of yellowtail flounder in the area from 1969 to 1973 do not reflect it, this flounder has been seriously reduced in abundance.

Catches of silver hake by foreign fleets in the area have been very large. This fishery also is regulated by ICNAF quotas. Domestic landings show no apparent effects from foreign fishing, but the catch of silver hake is determined more by demand than by abundance of the resource, and thus commercial catches will not reflect variations in abundance. Since foreign fishing began in the area, catches of winter flounder have been relatively small, although pulse fishing produced a large foreign catch in 1969 and a fairly large catch in 1972. The decline in

domestic catches of winter flounder may have been a consequence of foreign fishing, but the demonstrated existence of local stocks and wide natural variations in abundance make such a conclusion questionable. The domestic fishery for Atlantic herring in the area is negligible because there is little demand for adults of the species. The large foreign catches are apparently of little importance to the domestic fisheries, although it is not certain that the Maine sardine fishery will be unaffected. It would be interesting to know whether this large catch of an abundant species has had any indirect effects on other living resources of importance to the domestic fisheries. It appears that the domestic fisheries have been harvesting only a small fraction of the butterfish resource, but with the development of large foreign fisheries the resource now is believed to be fully utilized.

Reported foreign catches of northern lobster have been relatively small, but it has been suspected that incidental, unreported, catches are larger. Lobster supports an important traditional American fishery, and any foreign catch is a matter of concern. Recent declaration of lobster as a creature of the continental shelf by the United States may correct the situation, if other nations are willing to accept the rather strained definition as it applies to this species.

No foreign catches of black sea bass have been reported, except in 1964, when about 1,500 metric tons were listed, but sea bass migrate to the outer continental shelf in winter and incidental catches are suspected. Demand for squid is very limited in the United States, and this species has been much underexploited by the domestic fisheries, but squid are important in the diet of many resources of major interest to domestic fishermen. The large recent foreign fishery is of relatively minor concern to the domestic fisheries at present. At least 50 percent, and perhaps a greater proportion of the catch of the foreign squid fleet is butterfish.

Atlantic mackerel, like Atlantic herring and squids, is not in great demand in the United States. It has been a part of domestic strategy in negotiating with other nations that fish off this area to encourage them to concentrate on such abundant species of minor value to Americans. This strategy probably is less palatable to American recreational than commercial fishermen.

The domestic harvest of red hake probably is much underestimated by official catch statistics. This is the major species in the industrial trawl fisheries of Nantucket Shoals, a catch which is not reported by species. Red hake also supports a minor sport fishery. Most of the foreign catch of Atlantic cod comes from Georges Bank and north. In total catch domestic landings in the area have shown no obvious effects of foreign fishing. Sea robins are not of great importance to the domestic commercial fisheries of the area, but are apparently much more important in the sport fisheries. Only small catches of tilefish have been reported by foreign fleets, but the species occupies a very specialized habitat at the edge of the continental shelf, and incidental foreign catches are suspected. The domestic commercial fishery for sharks is small, but sharks are of interest to sport fishermen. The effects of the relatively large foreign catch on the sport fisheries are not known; the relatively large recent fisheries for bluefin tuna in the North Atlantic Ocean have brought that resource to a dangerously low level. Vigorous attempts now are being made to limit catches stringently.

In summary, it is clear that foreign fishing in the area has had measurable adverse effects on some fishery resources of interest to domestic commercial and recreational fishermen, and that foreign catches of some others are a matter of concern. In addition, as long as foreign fishing continues in the area, incidental catches of some resources will reduce to some extent the probability of measuring the effects of other variables on the abundance and condition of estuarine stocks. On the other hand, it must be noted that a number of important fishery resources of the area are not subject to foreign fishing, and that stocks of some of these, like soft clam and northern puffer, have declined in the last five years much more sharply than some which are taken by foreign fleets. This is not to say that foreign fishing is not having its effects, but it does emphasize the complexities of the situation and the need to pay more serious attention to domestic fishery management.

Social-political Issues

In the United States, the individual states, and sometimes counties or even towns, have broad jurisdiction over fisheries in adjacent waters. Local governments make the laws and regulations and are responsible for surveillance and enforcement. Federal jurisdiction over fisheries is restricted to international waters or to interstate commerce in fishery products. In the Middle Atlantic Estuarine Area the federal government takes the lead in ICNAF affairs and bilateral negotiations as they relate to the fisheries of the area, but this places many migratory resources under double jurisdiction, because important species like scup, summer flounder, sea bass, and others move seasonally between territorial and international waters.

International fishery management in the area has been criticized as inadequate or ineffective, but in reality this is too extreme a view. For one thing, it ignores what should be obvious, that domestic fishery management, which among other things includes pollution control, has failed almost completely. International agreement is difficult to achieve, and arrangements under ICNAF and the various bilateral agreements that apply to the area have not been perfect. However, it cannot be denied that the fisheries would have been in much worse condition today if the federal government had not entered into negotiations with other nations fishing off this section of the coast. The results of these arrangements have shown that the interests of the United States fisheries have been served best when we can present reasonable scientific evidence that a problem exists. Scientific research has been the basis of most of our international fishery agreements, but scientific evidence has played a very small role in determining fishery policy or in developing laws and regulations for most fisheries of territorial waters. This most important point has not been clearly recognized by many.

State and sometimes local governments in the area support scientific research on fishery resources and their environment. Some of the information developed has been used as a basis for regulating domestic fisheries, but usually fishery laws and regulations have been based on opinion rather than fact, and are much more likely to be concerned with who makes the catch than how the catch should be limited. In other words, domestic fishery management in estuarine waters is much more likely to be based on struggles between vested interests than on scientific objectivity. This contrast between international and domestic management strategies does much to explain why international arrangements, difficult as they are, have been much more successful than domestic.

Many state and local fishery laws and regulations tend to perpetuate inefficiency and prohibit or restrict efficient harvesting methods. This adds to the cost of catching fish, which is already relatively high because vessel construction, fishing gear, repair and maintenance, insurance, and other costs are greater than anywhere else in the world. In addition, most of the domestic fisheries suffer from overinvestment of capital and labor, another form of economic inefficiency. In the absence of scientifically-based catch quotas, or better still, limitations on numbers of fishermen and units of gear, there is no effective management of the resource. This, coupled with wide natural variations in abundance of individual resources, makes it virtually impossible to detect the effects of other manmade environmental changes.

Communication Between Fishery Interests

Commercial fishery interests in the United States have many protagonists and some antagonists. Commercial fishermen, processors, and distributors have many organizations, local, state, and national, which represent their interests in various ways. These include groups of fishermen, boat owners, unions, and trade organizations of various kinds. At the political level, commercial fisheries have surprisingly strong support, especially in such key fishing areas as the Pacific Northwest, Alaska, New England, and the Gulf of Mexico. In fact, some believe that in certain regions political interest and support at the national level is far greater than the economic value of the industry warrants.

On the administrative side the National Marine Fisheries Service of the Department of Commerce has the major federal responsibility for fishery research, development, and services to the commercial fishing industry and to recreational saltwater fishing interests. Other responsibilities reside in the Departments of State, Interior, Treasury, Agriculture, Labor and other departments and specialized agencies. Each state has an agency with prime responsibility for marine fishery management and research. Some coastal states have separate agencies for finfish and shellfish management, and often jurisdiction over anadromous fisheries is divided between coastal and inland fish and wildlife agencies. As already mentioned, research and management are sometimes further complicated by delegation of certain responsibilities to local governments.

In the Middle Atlantic Estuarine Area efforts have been made to coordinate research and management between states through the Atlantic States Marine Fisheries Commission (ASMFC), an interstate organization of more than 30 years standing, to which all 15 Atlantic coastal states belong. The Commission has made progress in certain directions, but has not yet succeeded in getting the states to cooperate in effective fishery management programs. The compact which created the Commission named the Fish and Wildlife Service of the Department of the Interior as its primary research agency. When the National Oceanic and Atmospheric Administration was created this function was transferred to the Department of Commerce. All of these agencies, groups, and key individual members exert influence in a variety of ways, through the communications media, by serving on advisory committees or com-

missions, testifying before congressional or state assembly committees or at public hearings, lobbying, and so on. Vested interests and inadequate or out-of-date information often stimulate controversy rather than solutions. It would be interesting to determine how much human energy and economic resources have been devoted to these ends, to no avail.

Sources of Information

Knowledge about the fisheries and the living resources and their environment resides in various forms in all individuals and groups described above, in conservation organizations, in universities, in the staffs of international fishery commissions, and in the United Nations family of organizations, especially FAO and UNESCO. The amount of knowledge available through such diverse groups is considerable, but it varies widely in accuracy, quality, and breadth, depending on the experience, competence, and interests of individuals and groups, and on the amount of information and expertise readily available to them. Between them, these individuals and institutions know, or have access to information on, abundance, distribution, and biology of the resources, including latent or underutilized species; the condition of those resources and the effects of manmade or natural environmental variables; fishing grounds and fishing methods; markets, prices, and economic structure of the industry; processing, distribution, and consumption of fishery products; imports and exports; the world fishery picture; and major problems of the marine fisheries.

None of this information is complete, and its adequacy and accuracy vary between resources and between specific fisheries. Much of it has been gathered by indirect methods and by scanty sampling and it may be difficult or impossible to estimate levels of accuracy. For example, statistics of commercial fishery landings published by the federal government, sometimes in cooperation with individual states, are generally considered to underestimate the catch, whereas the national surveys of saltwater sport-fishing probably have produced overestimates of the sport catch. Some attempts have been made to measure the accuracy of these estimates, and these have tended to confirm the statements made above, but these attempts have been confined to limited regions and short periods of time.

The literature on pollutants and their effects on fish and shellfish is voluminous, and has been accumulating at an accelerating pace. Experimental studies in the laboratory have demonstrated that many constituents of domestic and industrial wastes do specific damage to estuarine organisms. Such substances may kill fish and shellfish directly or exert less obvious, but sometimes much more damaging, effects on the resource as a whole, including modification of spawning habits, decreased growth and increased mortality of larvae and young, retention and transfer of human pathogens, concentration of heavy metals and pesticides, and increased incidence of deformities such as fin rot and crooked vertebral columns. It has been shown conclusively that DDT and other pesticides, developed to kill insects, are particularly harmful, in very low concentrations, to marine animals related to insects, such as crabs and shrimps. But pesticides kill or otherwise affect other invertebrates and fishes too. When it comes to measuring the effects of pollutants on fish and shellfish in the natural environment the problem is much more difficult because natural environmental variables, some seasonal, some longer-term, and fishing as well, have substantial effects on abundance. Against this background of fluctuating abundance it is nearly impossible to detect the effects of a single factor. Laymen are prone to be much more positive about cause and effect than scientists, but some scientists have further complicated the issues by making hasty judgments or by drawing unwarranted conclusions.

Much published work on effects of water pollution or of specific pollutants on fish and shellfish resources is fragmentary and inconclusive and not of much help for interpreting what is happening in the natural environment. Many agencies and individuals are doing research and gathering data. Some of the work is good, some mediocre, some trivial. Better coordination and review would be desirable. Since 1969 several useful reviews have been published. An example is "The Water's Edge," sponsored by the Institute of Ecology and the Woods Hole Oceanographic Institution in 1972. This and some other pertinent publications are listed in the bibliography, which makes no pretense of being comprehensive. The conclusions and recommendations in this report are worth study. Too often such documents are published and then forgotten.

Factors of natural human origin that affect survival, abundance, and general health of fish and shellfish in the natural environment are probably so numerous, and reinforce or buffer each other in so many complicated ways, that it probably is unrealistic to pretend that our understanding of cause and effect will ever be very clear. This is not necessarily a deterrent to effective control. If we know from laboratory studies that DDT or other similar compounds are lethal in small doses to blue crab or shrimps, then that should be sufficient cause to

decide that DDT should not be allowed to contaminate the waters of the Middle Atlantic Estuarine Area or anywhere else. If we know from laboratory studies and from analysis of animals collected in the natural environment that heavy metals, pesticides, and other toxins are concentrated in living tissues at levels higher than concentrations in the environment, that should be sufficient cause to prohibit additions of such substances to the waters of the coastal zone. If we know that addition of oxygen-demanding substances to a body of water will reduce the dissolved oxygen content to levels below that necessary for survival or for normal biological functioning, then that should be sufficient cause to prohibit excessive manmade oxygen demand in fish and shellfish spawning, nursery, or feeding areas.

Available data for understanding the effects of water pollution on commercial fishery stocks are reasonably good for some species or stocks of fish and shellfish. For example, it cannot be denied that water pollution destroyed the oyster industry of Greater Raritan Bay in New Jersey and New York, and is responsible for closure of most of the clam beds there. In the early 1960s a serious outbreak of hepatitis was traced to clams illegally harvested from Raritan Bay. There is no question that water pollution played a role in reduced marketability of shad from the Hudson River. In some places in the area it is clear that water pollution was at least partially responsible for declining runs of shad and other anadromous fishes. Aside from clear-cut examples like these, or accidents in which cause and effect is beyond reasonable doubt, presumption of pollution-associated effects on commercial fisheries is largely hypothetical. It is just as logical to suppose that the long-term upward trends in abundance of striped bass and blue crab in Chesapeake Bay were caused by nutrient enrichment from domestic wastes, as that the decline and recovery of blue crab stocks in New Jersey and New York were caused by heavy use and then prohibition of use of DDT. Data do not exist to support or to deny these hypotheses, and it is difficult to conceive of ways in which direct confirmation could be obtained.

SUMMARY AND CONCLUSIONS

In the 5-year period since the "National Estuarine Pollution Study" was completed landings of domestic commercial fish and shellfish in the Middle Atlantic Estuarine Area have almost doubled in weight. Although landings alone are not a very accurate index of abundance of the living resources of an area, other evidence demonstrates beyond reasonable doubt that, although the supply of some resources in the area has declined substantially since 1969, others are much more abundant today. Generally, the domestic commercial fisheries in the area appear to be in better condition now than they were five years ago, but this may be transitory and more apparent than real. Certainly, many stocks are much less abundant than they were. It has been demonstrated that the total living weight of fishery resources in the ICNAF area is substantially less than it was a decade ago.

It is tempting to attribute this general increase in abundance and catches to the beneficial effects of estuarine pollution control and abatement. Although there is no evidence to refute this hypothesis, neither is there evidence to support it. The short-term improvement in commercial fishing in the area must be reviewed against a long-term decline in catches of most food fish and shellfish, in which short-term fluctuations often have masked long-term trends. Among the most important sources of short-term fluctuations are some partly-understood and many unknown natural variations in the environment, the effects of which cannot be distinguished from the effects of manmade changes. Also unknown for most species are the effects of essentially unregulated domestic commercial fishing, and of deliberate or incidental catches by foreign fleets. Totally unknown, but certainly important, are the effects of removals of fish and shellfish by recreational fishermen. Sport catches of some species, such as bluefish and striped bass, are many times as great as the commercial catch. Unless these fishery-associated sources of attrition can be brought under control, the odds are high that domestic catches of traditional fishery resources will continue to decline in the long run, and that commercial fishing will continue to shift to underutilized resources. Such latent resources are not limitless, and they probably are underutilized either because markets are limited or the cost of harvesting is too high.

The extreme difficulty of measuring the effects of water pollution or pollution control on the commercial fisheries of the area as a whole need not be a deterrent to positive action. Molluscan shellfish are an important segment of the commercial fishing industry in this area, and they are worth preserving and enhancing. The molluscan shellfish resources also are important because they can be considered as endemic resources in the waters of each state, and therefore can be managed unilaterally without the need for interstate or international cooperation. Theoretically, management of these resources should be relatively easy, but as a practical matter it obviously has not been in most states of the area. In

some of the states it is not certain that a real incentive exists.

The area of bottom closed to shellfishing, and trends in closures or reopenings of such areas, may be a useful index of the condition of estuarine waters. If effective management of molluscan shellfisheries can be achieved, and the effects of natural environmental change and economic trends in the shellfish industries are sufficiently well understood, it may then be possible to evaluate the benefits of pollution control by monitoring estuarine shellfish grounds and measuring the condition of the living resource. In this connection, a better index of environmental quality on shellfish beds is needed, to replace the standard coliform bacteria count now in use.

It is possible that nutrient enrichment from waste disposal has increased the biological productivity of certain estuarine fishery resources in the area. If this is so, it was entirely serendipitous. The experience of the oyster industry in Great South Bay, N.Y., has demonstrated that uncontrolled additions of nutrients can also destroy an estuarine commercial fishery. For these reasons, and in the interest of public health as well, control and abatement of estuarine water pollution must have high priority. At the same time, the possibility of benefits to commercial and recreational fisheries from controlled addition of nutrients merits investigation. Where deliberate enrichment has been tried elsewhere, the results have been promising.

AUTHOR'S NOTE

Since this paper was written, information about commercial fishery landings in 1974 has become available. The figures are preliminary, and for some states have not yet been published, but it is clear that the upward trends noted for some estuarine species are continuing, especially for scup, summer flounder, and blue crab. In New York State commercial landings of blue crab were reported in 1974 for the first time in eleven years, and direct observations confirm the increased abundance of this species. Increasing abundance of summer flounder has been confirmed by a recent study of sport catches and effort in New Jersey (Festa, 1975). Black sea bass can be added to the list of resources increasing in abundance. The commercial catch of this species north of Chesapeake Bay has almost tripled since 1970, and sport catches are increasing also (Berrafato, 1975). On the other hand, the effects of foreign fishing on yellowtail flounder were first noted south of Cape Cod in 1974. Landings of this species dropped sharply from Rhode Island south.

Recovery of the blue crab resource may not be a good omen for the hard clam industry. Blue crab is a serious clam predator. Interactions between species, as populations wax and wane, create a shifting background against which the effects of water pollution are difficult to measure.

An encouraging note was sounded in July 1975 when the New York Department of Environmental Conservation announced that it would reopen some 9,200 acres of shellfish bottom in Long Island Sound because water quality has improved.

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OUR ESTUARIES AND COMMERCIAL FISHING TRENDS

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ABSTRACT

The estuarine habitat of fish and shellfish is eroded by both natural and man-caused environmental changes. Shrimp and menhaden are discussed principally, noting the effects on them of salinity, temperature, and turbidity. The soft-bottomed embayments peripheral to the estuaries offer preferred living conditions. They are more productive—and more vulnerable—than the open waters of the estuaries. Recommendations are made for preserving these estuarine habitats.

INTRODUCTION

Coastal marshes are among the most productive areas of the world, largely because they function as nutrient traps, occupy stable areas which are sheltered from destructive wave action and are nearly free of desiccation hazards. Nourishment is supplied by freshwater rivers and streams carrying loads of rich silt. At the same time, highly dependable tidal currents remove undesirable wastes and bring in larvae and oxygen-rich waters. Because of these characteristics, our coastal estuaries support a great variety and abundance of organisms. Perhaps even more important is that estuarine areas function as nurseries for a great many fish and other marine animals—including many commercial species—which spend most of their adult lives in deeper, offshore waters.

During 1973, the United States landings of seafood items totaled 4.7 billion pounds, valued at just over $900 million to the fishermen. Many of the important species of commercially important fish and shellfish depend significantly upon estuarine environment during at least a portion of their life cycle. Various authors have estimated that about two-thirds of our total commercial fish harvest is made up of estuarine-dependent species. The list is lengthy and, therefore, I am confining my examples to two important fisheries, penaeid shrimp and menhaden, which each support commercial operations along the east and gulf coasts of the United States. Each of these resources has residence in estuarine areas during portions of their life history, and are thus exposed to the potentially detrimental effects of estuarine degradation.

THE RESOURCES AND THEIR ENVIRONMENT

Shrimp

There are three commercially important species of shrimp in the gulf and south Atlantic areas: the brown shrimp, *Penaeus aztecus*; the white shrimp, *P. setiferus*; and the pink shrimp, *P. duorarum*. Two lesser important species are the seabob, *Xephopenaeus kroyeri* and the royal red shrimp, *Hymenopenaeus robustus*.

During 1973, the gulf and south Atlantic landings of penaeid shrimp were 207 million pounds, valued at $199 million to the fishermen.

Adult penaied shrimp spawn offshore. The eggs hatch within hours and the nauplii become part of the zooplankton. Within three to five weeks the young shrimp enter the bays and estuaries as postlarvae and there they grow rapidly, moving seaward and into the commercial fisheries within months.

In the estuaries, shrimp form part of the mobile benthos. Brown and white shrimp prefer soft muddy substrate, while pink shrimp prefer the firmer sandy bottoms. The species are omnivorous, eating plants, animals and organic and inorganic detritus. Penaeid shrimp are essentially an annual crop with only a small percentage of individuals surviving more than one year.

A number of factors influence the occurrence and success of spawning and the subsequent growth and survival of the young shrimp. Unseasonally low temperatures which occur following spawning are a significant factor in the survival of metamorphosing shrimp and postlarval shrimp in the estuarine nursery areas.

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Salinity appears to be a dominant factor in the distribution and growth of brown shrimp in the estuarine systems. Rainfall is the primary factor which influences bay and upper estuarine salinities. Runoff is the major factor influencing salinities in the lower estuaries. Barrett and Gillespie (1973) showed that years of above average discharge of the Mississippi River have been associated with poor production years for brown and white shrimp, while below average discharges resulted in good production years for the species. They noted that rainfall, combined with river water, may dilute estuarine and near-shore salinities to below the tolerance limits for penaeid shrimp and, therefore, substantially limit available optimum nursery areas. Other environmental factors such as turbidity, unseasonal meteorological conditions and pollution may affect shrimp populations.

No definitive studies have been conducted which relate the effects of turbidity to shrimp abundance and distribution. However, casual observations by several authors suggest that bays and coastal areas which are turbid produce the greatest concentrations of shrimp. Ingle (1952) and Viosca (1958, cited in Mackin, 1961) have both mentioned the fact that shrimp are apparently attracted to the turbid waters near shell dredges in Louisiana and Alabama. Kutkuhn (1966) felt that turbid estuaries and bays provided shrimp with both a supply of nutritive detritus and protection from predation. Lindner and Bailey (1969) established a qualitative relationship between turbid plumes and shrimp in the Gulf of Mexico using Gemini spacecraft photography and commercial catch statistics for the brown shrimp in the northwestern Gulf of Mexico. Their conclusions were conjectural because of the lack of "ground-truth" data on the fishing grounds.

Mock (1966) noted that the abundance of small white and brown shrimp was substantially greater along a natural coastline than along an adjacent area altered by bulkheading.

Menhaden

The United States landings of menhaden are comprised of four species: *Brevoortia tyrannus* and *B. smithi* on the Atlantic coast and *B. patronus*, *B. quentri* and *B. smithi* in the Gulf of Mexico. *B. tyrannus* dominate the catches in the Atlantic and *B. patronus* in the gulf. During 1973, menhaden landings for the Atlantic and gulf coasts totalled 1.9 billion pounds, valued at $73 million.

Commercial landings of menhaden in the Gulf of Mexico are largely 1- and 2-year-old fish. These ages also dominate in the Atlantic landings, although there are considerable volumes of 3-, 4- and 5-year-old fish in certain years.

Menhaden are euryhaline. The adults spawn offshore during the fall and winter and the larvae migrate inshore and live in the estuaries for five to 10 months, at which time they return to the offshore waters for further growth, followed by sexual maturity and spawning. Their early life history pattern is remarkably similar to that of the penaeid shrimp.

Reintjes (1970) noted "menhaden are an important component in an estuary. After they transform from the slender, transparent larvae to juveniles, they become filter feeders. They swim about in schools, usually with their mouths gaping open, to filter the small planktonic animals and plants from the water. They have a complex gill apparatus that forms a basketlike sieve that removes all but the smaller particles from the water. As the bulk of the organisms eat algae or the remains of higher plants, menhaden are principally herbivores. Menhaden are one of the few fishes (mullet is another) that live by grazing on the plants in the estuaries. They are at one of the lowest trophic levels near the bottom of the food chain and provide food, in turn, for nearly all the carnivores that are large enough to eat them. This then forms both sides of the coin: The role of estuaries in the life cycle of menhaden and the role of menhaden in the ecology of estuaries."

Reintjes and Pacheco (1966) discussed physical, chemical and biological factors affecting the survival and growth of young menhaden. Mass mortalities have been attributed to sudden temperature changes, low concentrations of dissolved oxygen, very high salinities, and toxic pollutants.

Gunter and Christmas (1960) noted that surface temperatures of coastal waters are a major factor in the migration patterns of menhaden. Harper (1973) stated that menhaden indicated a preference for clear water. However Tagatz and Wilkens (1973) found that more juvenile menhaden were caught in clear water estuaries at night than during the day while there was no such diurnal difference in turbid waters. They suggest that the turbid waters offer the young menhaden protection against predation. Kroger and Guthrie (1972) found indications of higher predation rates on young menhaden taken in clear water estuaries than in turbid areas.

Kemmerer et al. (1973) and Maughn and Marmelstein (1974) established a qualitative correlation between turbid plumes in the shallow Mississippi Sound observed from the ERTS-1 satellite and the commercial catch of menhaden. Surface salinity, temperature, and chlorophyll were also correlated with the manhaden catches made in turbid water. The cause of the apparent correlation was not

determined. However, the relationship is a well-known phenomenon that is utilized extensively by the fishermen and their spotter aircraft pilots in locating schools of menhaden.

Spotter pilots report that schools of menhaden are capable of creating turbid clouds ("dragging mud") as they pass over muddy bottoms. The fact that these clouds appear in water as deep as 100 feet as well as in shallow water, suggests that this behavior may be either a feeding response or a protective measure (Lichtenheld, 1970). Thus, in the shallow area of the Mississippi Sound, menhaden schools could have been responsible for the turbid plumes observed by Maughn and Marelstein.

The Estuaries

The destruction of estuarine zone wetlands as a result of natural processes and the activities of man is a continuing and serious problem. Except for a few estuaries in Alaska, every one of the nation's estuaries has been modified by man. Twenty-three percent have been severely modified, 50 percent moderately modified and 27 percent slightly modified. "The National Estuary Study," carried out by the United States Department of the Interior, concluded that the destruction of estuaries is proceeding at a rate that will spell their end within a few decades.

The most severe adverse environmental impact to estuaries has resulted from sewage pollution, dredging and filling to create land, channel dredging for navigation, industrial wastes, and ditching and draining wetlands. Additionally, there is river impoundment and flow control, pesticide pollution, solid waste disposal, seawalls, dike and levee construction to prevent flooding, mining and oil pollution. Chapman (1972) noted that for the south Atlantic, Caribbean and Gulf of Mexico estuarine regions, about 50 percent of the area has been moderately impacted and in the gulf, 34 percent has been seriously impacted. Important legislative steps have been taken in recent years to halt this irreversible trend.

PROBLEMS IN DETECTION OF ADVERSE EFFECTS

Despite documented degradation of the estuaries, there are few examples where changes in the overall productivity of shrimp and menhaden can be related directly to these environmental changes. One case may be the sharp decline in the shrimp production of Sabine Lake, Tex., concurrent with the completion of the Toledo Bend Dam on the Sabine River. A substantial portion of the runoff to the shrimp nursery grounds in the Sabine Lake area was reduced during late 1966 and 1967 during the filling of the reservoir. During the 5-year period following the closure of the dam, river discharge as measured at Ruliff, Tex., was one-third lower than an earlier 5-year period, 1955–1959, prior to closure. In addition, the seasonal pattern of runoff was altered substantially with the peak period occurring in April rather than May. The discharge data and catch information are shown in Figure 1. Shrimp catches from Calcasieu Lake, an adjacent estuary not under the influence of the Sabine drainage, are included for comparative purposes. There, the shrimp production has been maintained while the Sabine Lake production has fallen to near zero.

Such relationships are extremely difficult to isolate and verify on a real time basis. The measurement of the abundance of commercial species of fish and shellfish is, at best, a very crude science.

Measures of apparent abundance are always indirect. That is, an index of commercial fishing vessel success, adjusted for seasonality and standardized for vessel efficiency, becomes the standard for year-

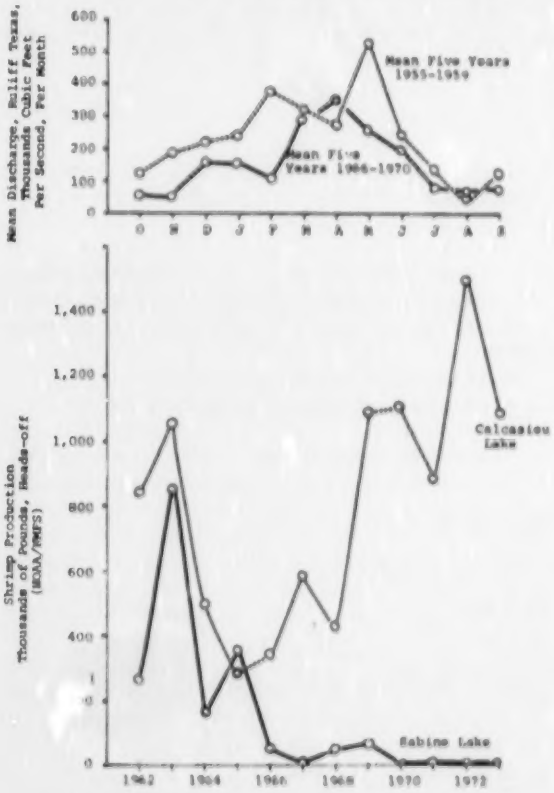
Mean Discharge, Ruliff Texas, Thousands Cubic Feet Per Second, Per Month
Mean Five Years 1955-1959
Mean Five Years 1966-1970
O N D J F M A M J J A S
Shrimp Production Thousands of Pounds, Heads-off (EXVA/PWPS)
Calcasieu Lake
Sabine Lake
1962 1964 1966 1968 1970 1972

FIGURE 1.—River discharge and shrimp production.

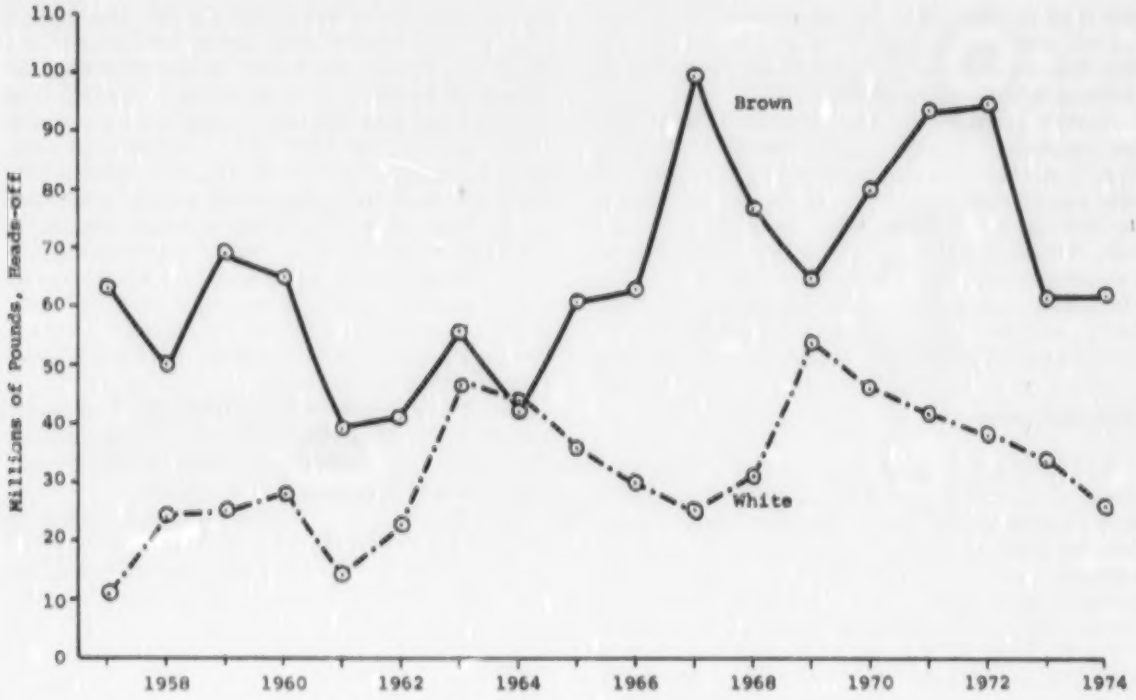

FIGURE 2.—Landings of brown and white shrimp, Gulf of Mexico ports, 1957–74.

to-year comparisons. However, the abundance of marine fish and shellfish populations are influenced by a complex of factors:

- Broad natural changes in marine climatology.
- Short-term variations in spawning and survival of young due to changes in ocean and estuarine conditions.
- Commercial fishing operations.
- Manmade changes in estuarine habitat.

National Marine Fisheries Service maintains long-term historical series on catch, effort and apparent abundance for gulf menhaden and shrimp fisheries. Changes in overall shrimp production levels are complex to analyze, as there are three principal species, taken by thousands of vessels, on a number of fishing grounds. Figure 2 depicts the historic catches of brown and white shrimp along the gulf coast since 1957. The 19-year trend in production is upward. However, substantial year-to-year fluctuations make it difficult to detect any real change in the average level of productivity until long after such a change has occurred.

The most recent data for menhaden is shown in Figure 3 (from Anonymous, 1974). Several important points are illustrated. First, there is a good long-term correlation between the amount of fishing effort and the resulting catch. Second, there appear to be cyclical deviations, since 1956, of the individual years about this average relationship. These fluctuations are about eight years' duration and are

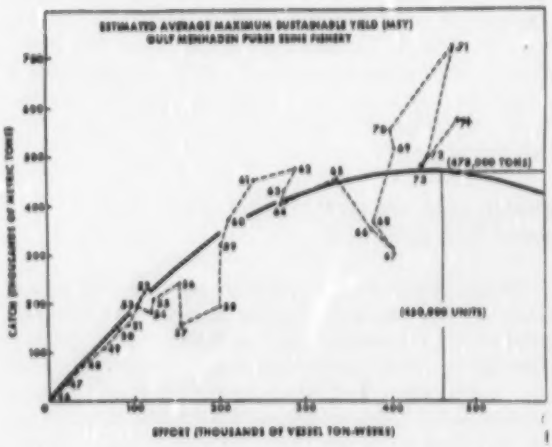
ESTIMATED AVERAGE MAXIMUM SUSTAINABLE YIELD (MSY)
GULF MENHADEN PURSE SEINE FISHERY
CATCH (THOUSANDS OF METRIC TONS)
EFFORT (THOUSANDS OF VESSEL TON-WEEKS)
(479,000 TONS)
(450,000 UNITS)

FIGURE 3

probably the result of changes in ocean and estuarine climate on the spawning and survival of the very young menhaden. The extreme values (1957, 1958, 1961, 1962, 1967 and 1971) exhibit an average deviation of 35 percent from the line of best fit. Thus, the trend in population abundance after the 1968 season suggests that the definite downtrend in catches since 1961 was signaling overfishing or detrimental effects of habitat degradation or a combination of both. However, the following year, catches began to increase again and peaked in 1971. With much the same level of effort, catches have been substantially lower in the 1971–1974 period. Is the present decline part of the cycle or is the decline signaling problems with the population? Obviously, we will not be able to say until four or five more years of information have been added to the data base.

The instability of marine populations has been noted by Longhurst et al. (1972). They emphasize the difficulties in sorting out and identifying the myriad of factors affecting marine fish populations. They also demonstrate that these changes can only be revealed and measured by deliberately mounted and well-sustained monitoring programs. They note a real lack of understanding that pollution monitoring schemes, in the ocean, can succeed only if the natural effects of the changing physical environment are both monitored and understood on a continuing basis. Natural fluctuations are often incorrectly ascribed to the effects of pollution; conversely, the effects of a modified environment frequently pass undetected in the system.

Erosion of habitat on a broad scale is gradual in nature and thus direct effects upon populations of commercial species of fish and shellfish are almost impossible to detect on a real time basis, amid the noise of short-term variability and long-term effects of fishing pressure and climatic change. Thus, we may be faced with the fact that these habitat modifications are completed and nonreversible by the time we can measure and document specific relationships for important species.

WHAT SHOULD WE DO

It is obvious that major research studies designed to document the direct relationship between estuarine habitat degradation and the deterioration of our major fisheries for shrimp, menhaden and other commercially important species will not be too useful in preventing these losses, but will prove largely an interesting historical documentation for later analysis.

What is required is an approach which states flatly that the shallow, turbid, soft-bottomed embayments in the interior of marsh areas around the periphery of the estuaries are the preferred habitats of many important migrating marine animals. These areas are much more productive per unit area than the open waters of the bays and estuaries. They represent about 30 percent of the total of 26 million acres of estuarine waters in the United States. These shallow areas, mostly less than six feet in depth, are the most vulnerable to man's activity.

Fishery dollar values per acre of nursery ground must be computed and adjusted for their renewability and for their direct and indirect impact upon our economy. Commercial values must consider not only the initial revenue to the fishing vessels (the traditional reporting method) but also the ripple economic impact upon the broad supporting infrastructure of the industry. Economists project that each dollar of primary industry income results in fivefold impact on our nation's economy. A dollar of landed catch value is divided among fishermen, shipyards, equipment and machinery suppliers, fuel dealers, provisioners, the insurance industry, the financial community, and many other smaller support elements. Sport-fishing and recreational values are more difficult to compute and compare with commercial values which are primary in nature. They are large, nevertheless, and the dollar impact (discounting the aesthetic values) is at least equal to that of the commercial industry.

Tihansky and Meade (1974) provide an excellent review of the problems associated with measurement of the economic values of estuaries to United States commercial fisheries.

The placing of a real fishery value, per acre, on the critical shallow estuarine areas, is not an easy task but it should and can be done on a region-by-region basis, utilizing currently available information. A research team of fishery biologists and marine economists, with practical business orientation, could expect wide-scale fishing industry cooperation, both commercial and sport, in such an endeavor. The results would provide agencies, legislature, and industry with a sound basis for decisions with respect to estuarine zone usage where conflicts of interest arise.

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LIMITING FACTORS AFFECTING THE COMMERCIAL FISHERIES IN THE GULF OF MEXICO

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ABSTRACT

The gulf coast, with 13 percent of the U.S. coastline producing one-third of the Nation's fisheries catch, is enriched by the Mississippi and many smaller rivers. The same river water that brings in food and fertility also brings pollutants from cities, industries and agricultural areas. So far, this pollution has not provably affected the commercial fisheries, except that closure of some bay areas by health authorities has hurt the oyster fishery. But over 95 percent of gulf fisheries production is based on species that depend on estuarine nursery areas and are therefore vulnerable to pollution and other man-made changes in estuaries. Fish kills and decreased reproduction in some areas warn of what could happen if conditions get worse. Research is needed on the costs as well as the benefits of man's activities, including pollution and pollution control, as population increases.

DESCRIPTION OF THE COAST OF THE GULF OF MEXICO

Inshore Waters and Estuaries

Some 1,000 miles of the gulf coast has an excess of precipitation over evaporation, and all of the nearshore gulf waters are strongly diluted by fresh water from floods or heavy local rains. All gulf coast rivers together flow into the gulf at the average rate of approximately 829,000 cubic feet per second or roughly 600,000,000 acre-feet of fresh water annually. Approximately 80 percent of this flows into the gulf on the Louisiana coast. Alabama contributes 8.3 percent, Florida 6 percent, Texas 4.4 percent, and Mississippi 1.3 percent of the fresh water entering the northern Gulf of Mexico.

The northern gulf is dominated by the Mississippi River, which flows into the gulf at the average rate of 620,000 cubic feet per second. The river water brings with it large quantities of dissolved nutrients, suspended organic matter, and nutrients absorbed on clay and silt particles, so that there is a broad area (over 400 miles) of enriched estuarine water surrounding the mouth of the Mississippi. Gunter (1963, 1967) called this the "Fertile Fisheries Crescent" and pointed out that 21 percent of the total fisheries catch of the United States was landed within this area. The percentage is higher now.

Estuarine waters on the gulf coast include large areas of low marsh that are flooded by fresh water in rainy weather and by salty water during high tide periods. Also, estuarine waters do not end at the "passes" (bay mouths), but continue into the gulf for variable distances. St. Amant (1973) estimated the gulf coast estuarine area, including only areas with water of salinity 5 parts per thousand (ppt) or higher, at 7.84 million acres (12,250 square miles). Chapman (1973) gave a figure of 12.4 million acres (19,375 square miles). Gunter (1967) counted 33 "bay systems and sounds" averaging about 550 square miles, or a total of 18,150 square miles, but pointed out that the actual area of estuarine waters normally includes parts of the gulf that have low salinities, and varies according to season and weather conditions from 17,000 to 20,000 square miles (10.88 to 12.80 million acres). (See Fig. 1.)

Commercial Fisheries of the Gulf States

Although it makes up only 13 percent of the total coastline of the United States, the gulf coast in 1972 produced 32 percent of the total U.S. fisheries catch, based on value, and 34 percent of the volume. In 1973, gulf coast fishermen landed 1,229 million pounds of marine and estuarine fish worth $63 million, and 246 million pounds of salt water shellfish worth $170 million. The total value of gulf fisheries landings was $223 million in 1972 and $233 million in 1973, based on prices paid fishermen at the dock.

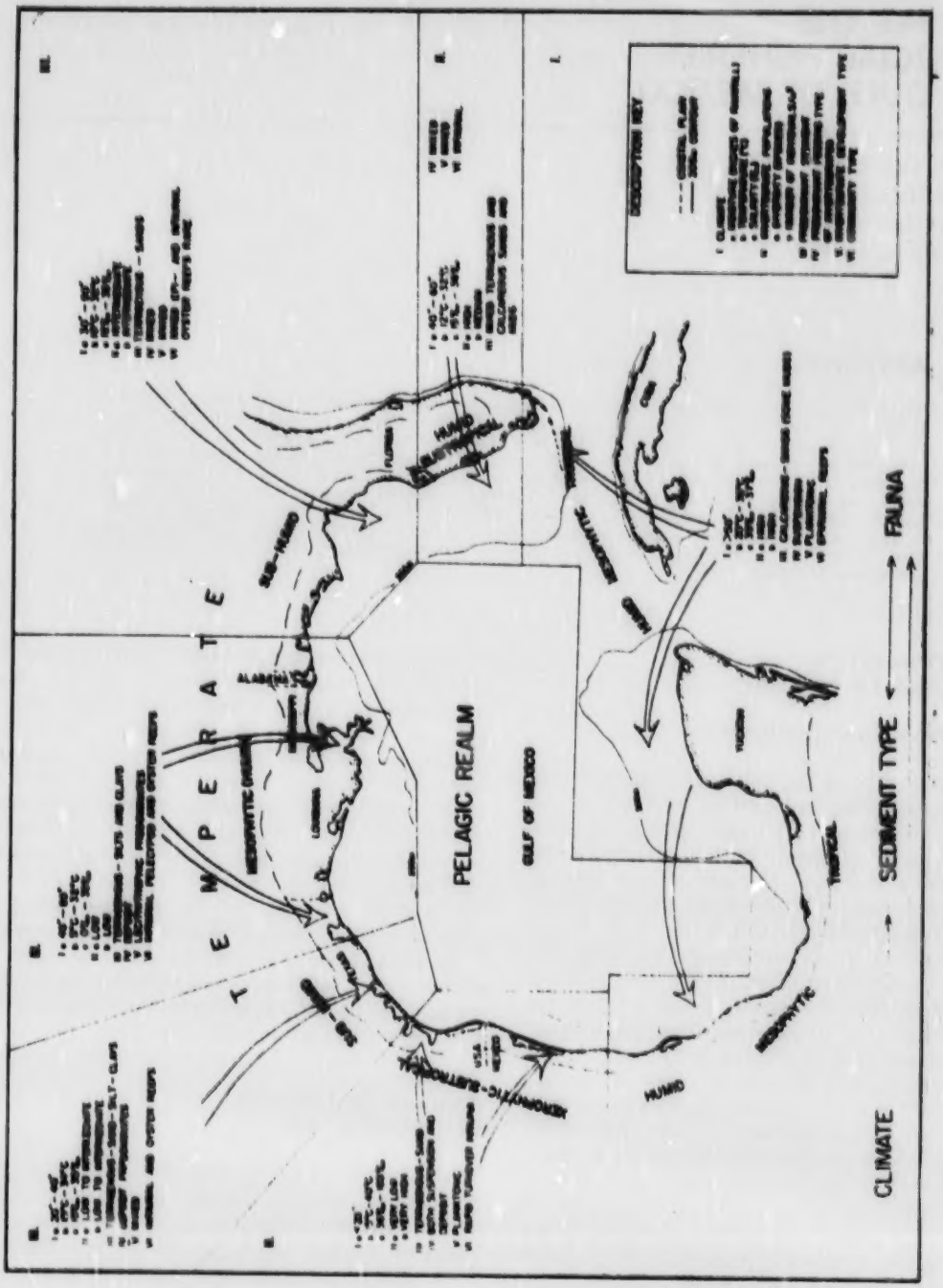

FIGURE 1.—Ecological chart: Gulf of Mexico (from Parker, 1974. Elsevier).

(Of course the wholesale value was higher, and the value of processed fishery products was much higher; retail value is roughly three times dock value.)

Several features of the gulf coast commercial catch are worth noting here.

(1) It is dominated by the shellfisheries, and especially by shrimp, crabs and oysters, usually worth three to four times more than the much greater volume of finfish.

(2) The finfish volume is dominated by menhaden. This industrial fish, which is processed to produce oil, fish meal and solubles worth ultimately many times the original value of the catch, is the number one fish of the United States in volume and among the top five in value. Approximately 60 percent of the U.S. menhaden catch is landed on the gulf coast.

(3) Nearly all of the gulf coast catch, including practically all of the menhaden, is made within the waters of the United States, or in international waters within a few miles of the U.S. coast. Of the important commercial fishes, only groupers and red snappers are caught mainly beyond the 12-mile limit, and they make up only 1 percent of the volume and 2 percent of the value of the total gulf coast catch.

(4) As Gunter (1967) has pointed out, 97.5 percent of the total commercial fisheries catch of the gulf states is made up of fishes and shellfishes that spend all or part of their lives in estuaries. A few species, such as the commercial oyster, live their entire lives in estuarine waters.

(5) Because gulf coast commercial fisheries are based on species that are mostly estuary-dependent, they are especially vulnerable to pollution. The fresh water of gulf coast rivers brings in residues of pesticides, defoliants, fertilizers, et cetera, used to produce crops on millions of acres of farmland. On the way to the gulf the rivers receive discharges from many city sewage systems and industrial plants, drainage from oil fields and mines, and so forth. So far, these contaminants do not seem to have reached the gulf in concentrations sufficient to conspicuously harm commercial fisheries, but that seems possible in the future if pollution continues to increase.

The typical gulf life cycle involves spawning in or near the gulf, in water of near-oceanic salinity, migration of the newly hatched juveniles to estuarine waters, then growing up in the shallows where young fish are protected from predators by vegetation, by poor visibility due to muddy water, or by salinity too low for most predacious fishes. These estuarine shallows are known as nursery areas. Some fishes leave the bays before becoming mature and others spend all or almost all of their lives in estuarine waters. The commercial fisheries can be maintained only by keeping the nursery areas productive.

Gunter (1967) and others have pointed out that most of the gulf commercial catch is made close inshore (inside the 12-mile limit, or within sight of shore), in waters that can be considered estuarine since they are affected by the fresh water and turbidity from rivers. For instance, the menhaden fishery, the most important commercial fishery in the gulf by volume of catch, is conducted entirely in estuarine waters of the gulf, according to Gunter (citing Christmas, Gunter and Whatley, 1960); catches are made in salinities from 6 to 32 ppt (compared to 34–36 ppt in the open gulf). Most of the drums, croakers, sea trouts, flounders, king whiting, and sheepshead are caught even closer inshore, or in the bays themselves.

The shellfishes, by far the most valuable part of gulf coast commercial fisheries, are even more estuarine than the finfishes. The principal commercial species of shrimp (white, pink, and brown) spawn in the gulf, but most of the progeny that survive to complete the life cycle are those that find their way into the estuaries and grow up in the low-salinity nursery areas (Venkataramiah, Lakshmi, and Gunter, 1974). Shrimp are worth roughly 10 times as much as all finfishes combined, excluding menhaden. The second most important crustacean, the blue crab, also spawns in the gulf and grows up in the estuaries; females return to the gulf (or lower ends of bays) when mature, but most males spend their entire lives in estuarine waters.

The third most important shellfishery is that based on the commercial oyster, which spends its entire life cycle in estuarine waters. Oyster production has been hurt more by pollution than any other fishery. When a bay is closed or condemned because of contamination by domestic sewage or industrial wastes, the oyster is the main species affected, and it is oyster fishermen and oyster farmers that are hurt (not to mention oyster dealers and consumers). Other commercial molluscs are of relatively minor value on the gulf coast.

What is the productivity of gulf coast estuarine waters in pounds of commercial fish and shellfish per acre? Depending on whether one accepts the 12.4 million acres of estuarine water (including gulf waters of lowered salinity) calculated by Chapman (1973) or the 7.84 million acres of St. Amant (1973), the present commercial production is 117 or 185 pounds per acre per year. Mullet, croaker, spot, sea trouts and drums could probably stand up under heavier commercial fishing. Present commercial catches of some species are small compared to mortalities from natural causes, as pointed out

by Simmons and Breuer (1962), and by Gunter in several publications. It seems possible that a commercial fisheries production of 200 pounds per acre per year could be reached and maintained in the gulf coast estuarine area.

NATURAL FACTORS LIMITING GULF COAST FISHERIES

Climatic and Physical Conditions

Temperature has two important effects on gulf coast fisheries: the high average temperature of the water hastens sexual maturity and shortens life of some fishes, and the extreme low temperatures of the shallow bays during northers cause mass mortality of fish every few years.

Gunter (1950) pointed out that such abundant fishes as the croaker, spot, spadefish, butterfish and harvestfish, which are important commercial food fish in the Chesapeake Bay and Middle Atlantic states, seldom reach marketable size on the gulf coast.

The most spectacular effect of temperature is the killing of millions of fish by extreme cold spells about once per decade in Texas (Gunter, 1941, 1945, 1952a, 1956; Simmons, 1957; Breuer, 1962; Simmons and Breuer, 1962) and in Florida (Storey and Gudger, 1936; Storey, 1937, and others). The best documented cold kill, in 1951, was estimated by Texas Game and Fish Commission biologists to have killed 60 to 90 million pounds of fish on the Texas coast. Simmons and Breuer (1962) stated that "Catastrophic freezes occurring about every 10 years have each destroyed more fish than have been harvested commercially for the past 50 years." Actually the bay water does not freeze, but drops quickly to about 4°C (39°F) and remains there for several days. Observed mortalities have included very few animals other than fish. Fish catches return to normal levels in two or three years.

Salinity extremes also affect some gulf fisheries adversely at times. The Laguna Madre of Texas and Mexico is one of the few places in the world where hypersalinity becomes so extreme as to cause mass mortality. Before the Intracoastal Waterway was dredged through the 120-mile length of the Laguna Madre of Texas, about 1949, this shallow lagoon, in a region where evaporation is normally twice as high as precipitation, often developed salinities of over 80 ppt, and sometimes over 100 ppt. The mass fish kills that were formerly caused by extreme hypersalinity have been practically eliminated by the improved circulation via the Intracoastal Waterway, according to Simmons (1957) and Hedgpeth (1967).

Low salinity caused by heavy rains during hurricanes sometimes kills fish and crustaceans in the Laguna Madre, where salinity may drop from 50 ppt to nearly zero on such occasions. In the more normal estuaries fish, shrimp and blue crabs are not killed by heavy rains or flooding, but are swept downbay by floods and escape into saltier waters by swimming with the current.

Oysters in normal estuaries are often killed by low salinity in all gulf states. The most spectacular oyster kills on the gulf coast occur in Mississippi Sound and the waters of the Louisiana marshland on the eastern side of the Mississippi River delta. In bad flood years it is necessary to open the Bonnet Carré spillway in order to prevent flooding New Orleans. Millions of oysters are killed by fresh water on these occasions, over an area of many square miles. Predators and parasites of oysters are also killed out. Then the oyster reefs are repopulated by larvae brought in by currents, and the next two or three years may see unusually large crops of oysters before the pests become reestablished (Gunter, 1952a, b, 1953, 1967).

Although such local freshwater kills seem at the time to be disasters, in the long run they are beneficial. The largest and densest populations of oysters develop in these areas that are frequently cleared of predators, pests and diseases, and not in the areas of higher and more stable salinity, because the same waters of near-oceanic salinity that are physiologically most favorable to oysters also favor a diversity of marine organisms, many of which are harmful to oysters.

For this reason, "salinity intrusion" in estuaries worries oyster biologists. Other fishery biologists also worry, fearing that increases in salinity will make the estuarine nursery areas less suitable for the survival and growth of juvenile fishes and crustaceans (blue crab, shrimp). Gradual increase in salinity, year by year, occurs when there is rise in sea level, sinking of land, and erosion of shores, making bays and passes wider. All of these processes are going on along the gulf coast, but faster in some parts than in others. Local subsidence of land makes estuaries larger, deeper and saltier.

In southeastern Louisiana the entire coastal area is sinking. New sediments used to be deposited in the swamps and marshes and along the shores by the annual floods of the Mississippi River. All distributaries except Atchafalaya River are now cut off by levees, so there are no longer new deposits of sediments (Morgan, 1973). The inevitable result of reduced freshwater inflow, increased land subsid-

ence and erosion, and rising sea level is an increase of salinity in the waters of the marshland estuaries. Consequently, marine animals, including predacious fishes that feed on juvenile fishes, crabs and shrimp, and the numerous enemies of oysters, penetrate farther and farther into the bays.

There are a few bays on the gulf coast with sandy shores and bottoms, and clear water. These are less productive than the typical gulf coast estuary, which has a mud bottom and highly turbid water rich in nutrients and organic sediments, either from a river or from surrounding marshes (Day, Smith, and Hopkinson, 1973; Odum, Zieman and Heald, 1973). It is the large area of muddy, low-salinity water that makes the northern gulf so productive of fish and shellfish.

The oyster is the only important gulf coast fisheries species that is known to be adversely affected by high turbidity and sedimentation; it is well adapted to turbid waters, but oyster beds are sometimes killed when buried in sediments. This happens naturally when floods deposit thick layers of sediment or storms shift the bottoms. It can also be caused by nearby dredging operations.

Gulf coast bays are so shallow (most are less than 10 and some less than 5 feet deep) that they are well aerated by wave action and seldom have pockets or layers of water deficient in oxygen. A famous exception is Mobile Bay. When deoxygenated water from deeper layers invades the shallows, thousands of fish, crabs and shrimp swim on the surface and concentrate in the shallows along the shoreline. This phenomenon has been known for at least a century as "the Jubilee" (Loesch, 1960). Apparently the deoxygenation of the water results from decay of plant debris occurring naturally on the bottoms, but organic pollution, if present, could make "jubilees" more frequent, more extensive, or more intense.

Red Tide (Phytoplankton Blooms)

A mass mortality of fish and shellfish on the southern part of the west coast of Florida occurs at intervals of several years, accompanying an area of discolored water. In recent years this has been called "red tide," although the water is not always really red. Since 1947 the gulf red tide has been known to be caused by a "bloom" of one particular dinoflagellate, *Gymnodinium breve*. All of the factors that must occur together to make this normally scarce organism explode into a population density of millions per liter are not yet known. During a red tide outbreak millions of fish die and many drift ashore, where they pile up on the beach in windrows and decay. Lesser red tide outbreaks have also been reported as rare phenomena on the Texas coast. Like the Mobile Bay "Jubilee," red tide outbreaks seem to be strictly natural phenomena that probably occurred when America was uninhabited. See Gunter, Williams, Davis and Smith (1948), Wilson and Ray (1956), Ray and Wilson (1957), Ingle and Martin (1971), Baldridge (1974), Wilson, Ray and Aldrich (1974), and Steidinger (1973, 1974).

Diseases of Fish and Shellfish

All animals have parasites and diseases. Fishes, crustaceans and molluscs are no exceptions, having the usual diversity of parasitic worms, protozoans, fungi, bacteria and viruses, plus some little crustacean parasites and parasitic algae. Gulf fishes are not known to have any disease or parasite that causes mass mortality or epidemics such as those that control sea herring in the Atlantic (Sindermann, 1970).

Oysters have many parasites and diseases, in various parts of the world. The most important parasite on the gulf coast is a fungus, or perhaps several closely related species of fungus, causing a tissue-destroying disease commonly known as "dermo." This disease starts to kill oysters in spring as soon as water temperatures rise above 20°C and continues to kill them until cool weather lowers water temperatures in autumn (Mackin, 1962). Mortality is highest in the higher salinities and at the higher temperatures. Annual mortality from this cause often exceeds 50 percent. This mortality is in addition to the more obvious killing by predators such as the stone crab, the blue crab, the boring snail, and several species of fish. All of these agents of oyster mortality are most abundant and most active in high salinity, which is the reason oysters survive better in the low salinities. Oystermen therefore fear "salinity intrusion" and oppose engineering activities that may cause increase in salinity.

MANMADE FACTORS LIMITING COMMERCIAL FISHERIES

Man has introduced new factors that limit commercial fisheries in gulf estuarine areas. These manmade factors will be discussed under three headings: engineering activities, pollution, and laws.

Engineering Activities

Most of the types of human alteration of coastal environment that are here called "engineering activi-

ties" have been discussed in a report by Cronin, Gunter and Hopkins (1971). That report also makes recommendations for the kinds of research needed on each of the problems caused by these works of man. Among the engineering activities analyzed in the 1971 report are: channel dredging, filling and spoil disposal, damming and diversion of rivers, levees and spillways, land-cut canals, jetties at passes between bays and the gulf, hurricane barriers, oceanic disposal of dredged materials and other wastes, "finger-type" (canal and fill) real estate developments, and various types of wetland modification.

To us it seems that the changes caused by engineering activities have possibilities of more serious damage to commercial fisheries than other effects of man's activities, because the changes tend to be permanent and irreversible. Fishery populations soon recover from overfishing if allowed to, and polluted waters return to normal when the pollution is stopped (even long-lasting pesticides and toxic metals becoming buried in sediments), but when open bay or marsh is destroyed by a real estate development that replaces vegetated shallows or marshes with stagnant, dead-end, vertical-walled canals, an area of nursery ground is partly taken out of production for many years (Trent, Pullen and Moore, 1972).

The gulf coast has the most highly developed estuarine and offshore oil fields in North America and perhaps in the world (with some 8 to 10 thousand wells in the gulf and thousands more in bays and marshes). The engineering activities in coastal oil field development in Louisiana and Texas involve the dredging of channels, including canals through marshlands, to develop fields in the marsh and bay areas. The damage done (especially to oyster beds) by activities of this type is probably more important than oil spillage. Exploitation of oil fields in the gulf, often many miles offshore, is conducted by drilling a number of wells from each drilling platform. If oil or gas is found, pipelines must be laid connecting the producing wells with shore installations. Shore installations must be built to receive and process petroleum production and to harbor, load and unload the vessels used in offshore operations. All of this necessarily causes some modification of the shore and shallow sea environment. Excepting oystermen, gulf commercial fishermen have not complained of any losses attributed to oil field operations other than damage to trawl nets from pipes, dropped tools, and other obstructions left on the bottom by the oil men.

Pollution

As a result of the increased utilization of the coastal zone for domestic residence, recreation and industrial production, the possibility of pollution of the environment has increased. The population of the gulf coastal zone has increased about 2 percent per year since 1960; at least a million people have been added during this period.

Increases in domestic wastes necessitate the construction of sewage treatment plants. Raw sewage released into rivers and eventually into the gulf, partially treated sewage, detergents, phosphates, nitrates, pesticides, petroleum hydrocarbons, and other compounds are all discharged into estuaries as "municipal wastes." Many of these compounds are directly toxic to commercially important species; some are toxic in combination with others; some cause excessive nutrient enrichment resulting in an abnormal proliferation of certain species, many of which are considered undesirable by man; and some have high biochemical oxygen demands (BOD) requiring large amounts of oxygen for their breakdown and producing oxygen-depleted water masses.

The development of recreational facilities to serve coastal residents and vacationers presents related problems. More than 2 million visitors vacation on the gulf coast of Florida alone. Certain types of recreational use place a heavy pollution load on a relatively small area. Marinas, for example, may result in large amounts of gasoline, oils, lead, phenols and organic wastes being added to the estuary. Boat use in Florida has more than doubled since 1960.

Industry has long recognized the value of estuaries for waste disposal. Among the industrial wastes which have been introduced into gulf coast estuaries are heavy metals, plasticizers including PCBs and phthalates, petroleum hydrocarbons, pesticides (organochlorines, organophosphates, carbamates and dioxins), and various other compounds. In most cases, relatively little is known regarding the toxicity of these materials to fish and shellfish. Virtually nothing is known of the sublethal effects of these compounds on chronically exposed organisms.

Agricultural practices may also result in pollution of the coastal zone through the addition of fertilizers and organic wastes. Pesticide usage on agricultural and livestock producing lands or in the abatement of insect nuisances in populated areas adjacent to estuaries has resulted in contamination of estuarine organisms, including some commercially important species.

The need for power to supply coastal inhabitants

has increased. Power plants require large areas of land and large volumes of water for their operation. Many commercially important species, especially their larval and juvenile forms, are trapped and killed on the intake screens of power plants, in their passage through the plant itself or in discharge ponds or canals where heated water (thermal pollution) and chemicals such as chlorinated algicides are released (Chesapeake Science, Volume 10, pages 125–296 (1969); personal observations). More specific and detailed information on pollution is presented in a later section of this paper.

Laws

In general, two kinds of laws limit commercial fisheries: public health laws intended to safeguard the health of the consumers of seafood, and conservation laws intended to prevent over-exploitation of commercial species.

Public health laws include those providing for inspection of shellfish, and the waters in which they grow, by state sanitation officers. If coliform bacteria (bacteria similar to those in the human intestine) are found to be too abundant in water or shellfish, or if inspection of the shoreline shows possible sources of pollution, a certain estuarine area or an entire bay may be closed, meaning that no shellfish can legally be taken in that area. Although such closures of shellfishing areas are often hard on local fishermen, in the long run they are beneficial to the fishing industry. These laws and their enforcement not only protect consumers, but help maintain public confidence in the wholesomeness of seafoods.

Conservation laws are more controversial. Often they are products of political pressures, and of prejudices and emotions rather than science. The worst restrictions on commercial fisheries are those demanded by sport fishermen to maintain a monopoly for themselves. Pressure by sport fishermen has resulted in closing Texas bays to netting for fish. There is even a movement on foot to outlaw the sale in Texas and Louisiana of such marine fishes as spotted trout and red drum because they are game fishes. As Gunter and other fishery biologists have pointed out, at least some food and game fish populations are probably underfished at present, and the numbers of fish killed by natural causes (freezes, red tides, predators, and old age) may far exceed those caught by all sport and commercial fishermen combined.

TRENDS, EFFECTS OF TRENDS, AND SPECIFIC CASES OF POLLUTION

In 1959 Gordon Gunter reported on "pollution problems along the gulf coast." He mentioned sewage pollution, pulp and paper mills, fish processing plants, chemical plants, sugar refineries, oil refineries, and so forth, but commented "I am happy to say that the gulf coast is probably freer from pollution than any other area of the United States coast at present." Gunter stated that Galveston Bay was "the only heavily industrialized area on the coast of the Gulf of Mexico," but pointed out that 38 percent of the sport fishing in Texas was done in the Galveston Bay area, that 36.5 percent of the Texas catch of four common sport fishes was caught in Galveston Bay and its branches, and that this area still contained some of the best oyster reefs in Texas. The conditions in Galveston Bay are nearly the same today. Approximately half of the bay area has long been closed to shellfishing because of sewage pollution, yet the remaining half has produced more oysters annually during the last decade than in any period prior to 1960, and there is still excellent sport fishing in the bay.

Biglane and Lafleur (1967) revealed the appearance of some gulf coast pollution problems not mentioned by Gunter, especially the beginning of fish kills in Louisiana fresh and coastal waters that were shown by U.S. Public Health Service scientists to be caused by insecticides such as endrin. The other pollution problems they mentioned were attributed to what we have called engineering activities: leveeing of the Mississippi River, change of marshland drainage patterns by dredged channels, and so forth.

The most obvious effect of pollution is the direct mortality in what has been termed "fish kills." According to Environmental Protection Agency (EPA) statistics, the numbers of reports of fish kills and the number of fish killed have increased since the survey was begun in June 1960. The number of fish kill reports increased from 465 in 1969 to 634 in 1970 and to 860 in 1971. There has also been a general upward trend in estimated numbers of fish dying in fish kills, at least through 1971 (when 74 million fish were reported killed).

Every one of the Gulf Coast States has experienced significant fish kills which have been attributed to agricultural, industrial or domestic wastes. Since 1965, either municipal wastes (sewage) or industrial wastes have been reported as the principal cause of fish kills in the United States for each year. In 1971 the major identifiable cause of fish kills was reported to be "sewage system wastes" with "pesticides"

second at about one-half that level (US EPA, 1972). These data do not exactly pinpoint the problem since municipal sewage contains significant amounts of petroleum products, metals, pesticides, and other industrial materials as well as organic wastes.

Most fish were killed in fresh water from 1965 to 1969. However, in 1971 there was a decrease in the number of dead fish reported from freshwater bodies and a sharp increase in the numbers from estuarine areas for the first time since these statistics were first compiled (1960). During recent years, a single kill or relatively few accounted for a considerable percentage of the total kills for that year. Statistics for 1971 reveal 29 million fish killed in 12 incidents in Florida (Escambia Bay) and 16 million in six incidents in Texas (Galveston Bay).

Three points need to be made here. The first concerns the kinds of fish killed. When kills are caused by sewage pollution, the first fish killed in estuaries are likely to be menhaden, which though important because of their abundance, are cheap fish (worth four cents a pound in 1973). Second, the numbers of fish reported killed on the gulf coast by pollution are less impressive when compared with the 50 to 90 million pounds (perhaps equal to 200 to 360 million fish) killed by a single freeze on the Texas coast in 1951, or the 500 million fish estimated to have been killed by a single red tide outbreak off Florida in 1946–1947 (Gunter, Williams, Davis and Smith, 1948), not to mention the 1.2 to 1.8 billion pounds of fish caught annually by commercial fishermen and the 400 to 500 million pounds taken by sport fishermen. Third, fish kills are important not because of the loss of fish, but because they serve as warnings that the environment is in danger. If the condition that caused the kill is only temporary, other fish will quickly replace the ones killed and there will be no real loss. If it is persistent, replacement may be prevented, or the replacements may be less desirable species. Massive fish kills impress the general public much more than increases in bacterial counts or metal content of fish and shellfish, and are more likely to stimulate action against degradation of the aquatic environment.

Another demonstration of the effects of pollution of the environment on commercial fisheries is the closing of estuarine areas to the taking of shellfish. In most cases, closure is ordered by the state department of health based on bacteriological criteria. These criteria are based on levels determined by the state and on levels allowed by the Food and Drug Administration (FDA) for interstate shipment.

The largest Texas area permanently closed to shellfishing is in the Galveston Bay area, nearly half of which has long been closed. There have been no significant changes in the acreage permanently closed in Texas bays since 1970, but some bays have been closed temporarily after floods, as in the spring of 1972 (Texas State Department of Health). The Louisiana Department of Wild Life and Fisheries (Perret et al., 1971) reported 139,905 acres closed to shellfishing, and in 1972 additional areas were temporarily closed after flooding (NOAA-NMFS Louisiana Landings, 1974). Varying acreages of Mississippi bays have been closed in recent years; Biloxi Bay has apparently been permanently lost for oystering (Christmas, 1973). The Alabama Conservation Department reported almost 74,000 acres permanently closed to shellfishing, with additional acreages temporarily closed when floods carried sewage contamination into other areas (Crance, 1971; May, 1971). During 12 of the 18 years from 1952 to 1970, lower Mobile Bay was closed for taking of shellfish at least part of the year because coliform bacteria counts exceeded 70 per 100 ml of water. Each such closing causes economic loss; the loss in 1969 was estimated to be $500,000. In 1972, after floods, Mobile Bay oystering areas remained closed 217 days (NOAA-NMFS Alabama Landings, 1974). McNulty et al. (1972) reported that on the Florida gulf coast 170,698 acres of estuarine areas were closed for shellfishing.

Any general trend that may exist in the closing of estuarine areas to shellfishing on the gulf coast as a whole is obscured by the local changes (opening and closing) from year to year or month to month as pollution conditions change back and forth. Closures were especially harmful to the oyster fishery in 1973 because of extensive flooding, but the increased production in 1974 tended to compensate for this.

Pollution of estuaries, besides causing the closing of fishing areas, also results in the seizure and condemnation of commercial fisheries products when pollutant residue levels or bacterial counts are above the tolerances established by the FDA for interstate shipment. The contamination of estuarine species by various pollutants has been well documented. Residues of the DDTs (including DDT, DDD and DDE), dieldrin, mirex and other organochlorine insecticides have been detected in oysters, other bivalves, blue crabs, shrimp and fishes collected from estuaries along the gulf coast (Butler, 1973; Petrocelli et al., 1973, 1975a, 1975b; Childress, 1968, 1971). DDT and PCB residues have been detected in the tissues of fish, crabs, shrimp and squid collected from offshore waters of the Gulf of Mexico (Giam et al., 1972).

Butler (1973) in a monitoring study during the period 1965 to 1972 found that DDT was the most common pesticide and dieldrin the second most com-

mon in molluscs. The incidence of DDT residues (the percentage of samples in which DDT or products of its decay could be detected) was 63 percent and that of dieldrin 15 percent. Butler described a general decline in both the number and magnitude of DDT residues in oysters over the 7-year period. The data for the gulf coast samples are as follows:

State	*Frequency (%) of residues detected in samples and (maximum value in ppb)*				*Date of survey*
	DDT		*Dieldrin*		
Alabama	100%	(616)	18%	(21)	1968–1969
Texas	73%	(1249)	18%	(87)	1965–1972
Florida	62%	(5390)	7%	(28)	1965–1972
Mississippi	61%	(135)	4%	(20)	1965–1972
Louisiana	no data				

Heavy metal residues have also been found in the tissues of estuarine species (Saha, 1972; Eisler 1973). According to public health officials, relatively few seizures or condemnations of commercial fishery products due to pesticide or heavy metals contamination are made compared with seizures resulting from elevated bacteriological levels. However, as research better defines the sublethal effects of these compounds, human tolerance limits, as set by law, may be lowered thus increasing the possibilities of commercial fishery products exceeding these levels. Assuming no further input of these compounds into estuaries, this situation would significantly decrease the amount and value of marketable products. Any increases in the levels of pollutant added to estuaries in the future would even further complicate this problem.

UNKNOWN EFFECTS

Possibly the most insidious effect of pollution on the commercial fisheries is one which is the least understood and is only now being considered on a broad level. This is the effect of pollution on the ability of organisms to reproduce and for their larvae and juveniles to develop normally to mature adults fully capable of successful reproduction.

It has been hypothesized that high concentrations of DDT in the ovaries of sea trout are responsible for declines in their population through decreased reproductive success or decreased survival of juveniles on the Texas coast (Butler et al., 1972, Childress, 1971). Monitoring of pesticide residues in oysters (*Crassostrea virginica*) and fish of various species from bays on the Texas coast began in July 1965 and January 1967, respectively. Childress (1965, 1966, 1968, 1971) reported DDT incidence in oysters remaining at about the same level from 1965 to 1967 with a slight decrease from 1967 to 1968. The incidence of dieldrin residues (the percentage of oyster samples in which dieldrin residues could be detected) increased from 1 percent in 1965 to 23 percent in 1967. The incidence of endrin residues increased from .02 percent in 1965 to 1 percent in 1966–1967 in the oysters sampled by Childress. (The oyster is a good test animal for monitoring pesticides or metals in the estuarine environment because it filters huge quantities of water and tends to accumulate materials in its tissues.)

During this study period Breuer (1971, 1972), reported on the historical and recent abundance of spotted sea trout (*Cynoscion nebulosus*) in the lower Laguna Madre. Sea trout juveniles were abundant in 1958–1959 but declined in abundance through the 1971 sampling period. In 1969, only 21 juvenile sea trout were identified in a total of 21,473 marine organisms collected. In 1971, five juveniles and no adults were captured using the same sampling techniques. Pesticide residue analysis of juvenile menhaden, on which sea trout feed, revealed whole body concentrations of 1.520 ppm of DDT in 1966 and 5.180 ppm in 1967 (Breuer, 1971). Ovaries of adult sea trout in the Arroyo Colorado area (lower Laguna Madre) contained DDT residues as high as 7.980 ppm, dieldrin residues to 0.170 ppm and endrin levels of 0.054 ppm (Childress, 1968). Distribution of insecticide residues (ppm) in these fish were:

	DDT	*Dieldrin*	*Endrin*
ovaries	6.280	0.028	0.017
brain	0.958	—	—
liver	7.560	—	—

From the data it appears that DDT has had an adverse effect on the reproductive success of the local sea trout. It should be explained that the Arroyo Colorado is a waterway draining part of the intensely cultivated farmland and citrus groves in the irrigated area known as "The Valley" in Texas.

Behaviorally, it has been reported that some aquatic species are actively attracted or repelled depending on other interacting parameters by pollutants such as copper and petroleum hydrocarbons (Kleerekoper, et al., 1973; Jacobson and Boylan, 1973).

Still another effect which has recently come to light is the interaction among pollutants and between pollutants and natural stresses. Nimmo (pers. comm.) and recent work by Petrocelli (not yet published) have shown that salinity shock, such as occurs in the estuary in the course of heavy rainfall

or river flooding, combined with exposure to sublethal concentrations of pollutants results in mortalities not predictable on the basis of the salinity change or toxicity of the pollutant alone (Petrocelli et al., unpublished data; Anderson et al., 1974; Roesijadi et al., 1974). In some cases, this effect can be attributed to changes in the physiological response of the animals to these stresses. For example, shrimp exposed to heavy metals or PCBs and salinity shocked have been shown to be less efficient than controls in the regulation of blood chloride ion levels to compensate for these changes. Overstreet (1974) described a kill of estuarine fishes, mainly mullets, in Mississippi, which was apparently caused by interaction between low salinity and low temperature, possibly complicated by pesticide contents somewhat higher than in surviving mullets. Interaction has also been observed in the case of other physiological factors. For example, crustaceans during molting are much more susceptible to pollutants than are the same animals during the intermolt stages (Petrocelli et al., 1974, unpublished data). In other studies, sheepshead minnow (*Cyprinodon variegatus*) juveniles chronically exposed (63 days) to sublethal concentrations of mercury (1.0 ppb) were observed to have a respiratory rate which was significantly lower than that of control fish (Petrocelli et al., 1974, unpublished data).

The biological effects of petroleum and its products are still largely unknown, in spite of all the literature. The problems are complex because the hundreds of crude oils are complex, each containing hundreds of compounds, and refining adds many more. Crude and refined oils change upon exposure to air and water, in different ways under different conditions. Though difficult, the many problems involved in the biological effects of petroleum products should be studied by more laboratories. Atlantic coast oil fields will soon be added to those in the gulf and Pacific. More important, we will soon have supertanker ports with possibilities for much greater oil spills than have ever occurred up to now.

The famous Santa Barbara oil loss was estimated at 3 million gallons (Holmes, 1969). The largest of the four big oil spills in the Gulf of Mexico fields was about 5 million. According to a 1974 report of the U.S. Bureau of Land Management, all oil losses of 50 barrels or more in gulf fields during the 10-year period beginning 1964 add up to 320,000 barrels (13.4 million gallons) out of 2.9 billion barrels produced. But these figures are dwarfed by the estimated 90,000–100,000 tons (27 to 30 million gallons) of crude oil spilled into the English Channel by the "Torrey Canyon" (Smith, 1970), which was smaller than the new supertankers. Nevertheless, if we continue to import oil we will have supertanker ports, so we should learn more about the ecological effects of petroleum.

To look at the bright side, the thousands of oil wells now producing in the gulf and in gulf coast bays have not caused any decline in commercial fisheries production. Louisiana, which has most of the oil wells, has had its largest production of shrimp and menhaden during the years when gulf oil fields were developing. (Of course we all know this was a mere coincidence, but would we have known this if catches had declined during that period?) Oyster production has suffered, mainly from damage done by channel dredging and other engineering activities and from loss of sales when oysters taste oily (as they do occasionally). The Louisiana experience shows that the petroleum and fishery industries can coexist, even though not in perfect harmony. Earlier studies on oysters in oil fields are summarized by Mackin and Hopkins (1962), and more recent reports on ecological effects of oil are reviewed by Moore, Dwyer and Katz (1973) and by Mackin (1973). See also Anderson, Neff, Cox, Tatem and Hightower (1974) and other reports by Anderson, Neff and colleagues, still in press but available as reprints.

NEEDED RESEARCH AND FUNDING

There appears to be a great deal of "fad" research being conducted. Particular pollutants are picked up, some papers published and then work begun on other compounds before definitive research has been completed. Recent examples of this include DDTs, then other organochlorine pesticides, metals, organophosphates, PCBs, petroleum hydrocarbons, plasticizers such as phthalates, et cetera. National priorities should be determined in workshops which include ecologists, physiologists, and analytical chemists who are interested in working with environmental pollution problems. These priorities should then be implemented through research grants or contracts. A central clearing office should be established to coordinate the whole effort, to insure adherence to overall goals and to prevent the current wasteful and unnecessary duplication of work funded by the various governmental agencies.

Funding should be on a minimum of a two year basis so that time and efforts will not be wasted in unnecessary proposal and report writing or in switching projects to obtain continued funding. Progress should be reviewed periodically (every six months), unproductive programs dropped, and program gaps filled by addition of new programs.

With regard to directions for research, it would be helpful to study sublethal as well as lethal effects of pollutants on physiological responses. It is the physiological responses that determine survival in the environment (as opposed to the laboratory), get the animal to its spawning grounds, determine the success of mating and egg-laying, and so forth. Survival in the laboratory does not necessarily mean that survival in nature is probable. For the same reason, effects of manmade factors on biochemical composition and activity, microscopic structure of tissues and cells, and other indicators of health of estuarine animals should be studied. Ability to reproduce and success of larval and juvenile stages in surviving, growing and developing, obviously should be included in any study of lethal and sublethal effects. Toxicity studies should include tests on animals at various stages of development, not just adults. Multifactor interactions (effects of various combinations of pollutants, salinity and temperature, for instance) should be more enlightening than studies of effects of single factors. To get still closer to the complex situations found in nature, field experiments (for instance, holding animals at various distances from a suspected toxic source, in pens or cages) are often useful. The object of all such studies is to find out what happens to the organisms in nature. In order to do this properly, field surveys and catch statistics, field experiments, and laboratory experiments are all needed, and should preferably all be done by one coordinated team.

Funding should be on the order of at least $100,000 per year for a moderately ambitious research project at a major university. This level would allow part-time salary for the principal investigator, salaries for about four graduate research assistants and technical help, small pieces of equipment and supplies. Narrower scale projects could be funded at a reduced rate. Broader projects including both field and laboratory studies would require more funding, roughly in proportion to the number of people involved.

SUMMARY

A natural pollutant, fresh water, excludes most marine animals from the inshore waters and shallow bays along much of the northern coast of the Gulf of Mexico. This makes these waters ideal for survival of animals that can tolerate lowered salinity, including the young of fishes and crustaceans that require gulf salinity when mature. Most species important in gulf fisheries spawn in the gulf or saltier bay areas, but the young migrate to the less saline estuarine waters and grow up in these nursery areas.

The same river water brings in the huge quantities of food, in the form of dissolved and suspended organic substances, that enable the northern gulf to produce 32 percent of the U.S. commercial fisheries production on 13 percent of the coast. The number of species is held down by the extremes of temperature and salinity, the high turbidity close to shore, and the frequent kills of marine species from natural causes: freezes, floods, red tides, et cetera. Dense populations of a few species are essential for good commercial fishing. Most gulf species are prolific and have short life cycles—1, 2, 3 or 4 years from reproduction to reproduction so that losses from natural disasters or from heavy fishing pressure are soon made up.

Unfortunately, the same river water that reduces salinity and contributes food also brings in manmade pollutants, both microbial and chemical. Man further endangers the fisheries by engineering activities—leveeing, dredging and filling, damming and diverting streams, and so forth. Gulf coast fisheries are especially vulnerable to such manmade changes because most of the catch is made within 12 miles of the shore, and over 95 percent of it consists of species that depend on estuarine nursery areas.

Destruction or poisoning of nursery areas could destroy most of the gulf coast commercial fisheries. So far, these fisheries have not been perceptibly hurt, excepting the oyster which is confined to estuaries. The damage to the oyster fishery has been mainly from engineering works, from oil contamination occasionally making oysters in a small area unsalable for a few weeks or months, and from closure of bay areas by health authorities because of sewage pollution.

Although gulf commercial fisheries other than the oyster fishery have apparently not yet been hurt by manmade changes, including pollution, they are in danger. There have been warning incidents—pollution kills of fish in a few areas, apparent prevention of reproduction of sea trout because of pesticide concentration in one area—to show what can happen. If shores continue to be altered by real estate developers, stream flow continues to be interfered with by levees, dams and diversions, and man's wastes and poisons continue to increase, the gulf commercial fisheries will eventually be badly hurt. Research is needed to determine when the costs of man's activities reach the point where they exceed the benefits. We do not yet know all of the environmental costs, in a quantitative way, as we should. In the meantime, every effort should be made to avoid engineering activities and polluting that we know to be harmful.

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DREDGING EFFECTS

MAN'S IMPACT ON ESTUARINE SEDIMENTATION

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ABSTRACT

Estuaries are ephemeral features on a geological time scale being rapidly filled with sediments. Although most estuarine sedimentation rates are naturally high, man's activities have greatly accelerated the rates of filling of many estuaries, thus shortening their geological lifetimes. More importantly, the increased influxes of fine-grained sediments have degraded some estuaries, or segments of them, to the extent that their useful biological and recreational lifetimes have been cut drastically shorter than their geological lifetimes.

Much more effort should be directed at reducing the most manageable source of sediment to most estuaries—soil erosion. This would not only result in an improvement of water "quality," but would, within a few decades, result in significant reductions in the amounts of dredging required for channel maintenance. Dredging will, however, continue to be a persistent problem because the supply of sediments cannot be eliminated.

A new approach to dredging and spoil disposal is required. Regional plans must be developed to ensure that maintenance channel dredging can be carried out without prolonged delays. The present standards for characterization of dredged materials do not have a sound scientific basis, and should be reevaluated. While they were intended to be environmentally conservative, they may be unduly restrictive.

INTRODUCTION

Estuaries are the major sites for the accumulation of sediment along our coastline. Their positions at the mouths of rivers make them the ready recipients of sediment eroded from the land, and the characteristic circulation patterns produced by the mingling of fresh water from the land and salt water from the sea that takes place in estuaries makes them effective sediment traps. The rate of sediment accumulation in estuaries, which is already naturally high in many situations, has been increased by man's activities.

The primary purposes of this report are: (1) to review some of the characteristic estuarine sedimentation processes; (2) to look at some of the ways in which man has altered these processes; (3) to assess the significance of the effects of these changes on the estuarine milieu; and (4) to recommend the types of research needed for significant advances in our understanding of estuarine sedimentation processes.

For this discussion, we adopt the definition of an estuary most commonly used by physical oceanographers—an estuary is a semi-enclosed coastal body of water freely connected to the ocean within which seawater is measurably diluted by freshwater runoff from land.

SEA LEVEL, SEDIMENTATION, AND THE LIFE EXPECTANCY OF ESTUARIES

All present day estuaries were formed by the most recent rise in sea level which began approximately 15,000 to 18,000 years ago. During the last glacial stage (the Wisconsin) the level of the sea was about 125 m (410 ft) below its present level (Fig. 1) and most of the continental shelves of the world were exposed to the atmosphere. With the melting and retreat of the great ice sheets, sea level rose, rapidly at first, from about 15,000 years ago until about 9,000 years ago when it reached a position approximately 20 m (66 ft) below its present level. By 3,000 years ago the level of the sea was within 3 m (10 ft) of its present position, and since then the sea has risen even more slowly, averaging less than 1 m per 1,000 years.

The rising sea invaded numerous coastal embayments and produced estuaries in those that received enough fresh water to measurably dilute the encroaching seawater. Many of these coastal basins were former river valley systems. Examples are Chesapeake Bay, Delaware Bay, and the estuaries around the Mississippi Delta. Other basins, formed by glacial scour, were the fjords such as those found along the coasts of Alaska and British Columbia.

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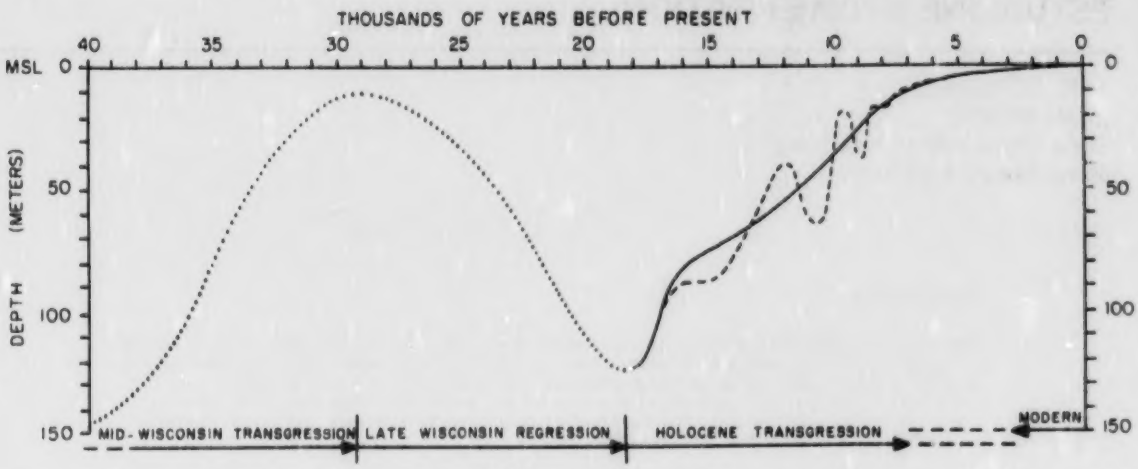

FIGURE 1.—Fluctuations of mean sea level from present to 40,000 before the present (B.P.). The curve was compiled from published and unpublished radiocarbon dates and other geologic evidence. Dotted curve estimated from minimal data. Solid curve shows approximate mean of dates computed. The dashed curve is slightly modified from Curray (1960, 1961). Probable fluctuations since 5,000 years B.P. are not shown (J. R. Curray, Late Quaternary History, Continental Shelves of the United States in the Quaternary of the United States, 1965).

Wave action and littoral drift formed bars off the mouths of some rivers thereby creating embayments which were later transformed into estuaries. Examples are Pamlico and Albemarle Sounds. Still other coastal basins that later became estuaries were formed by tectonic processes. San Francisco Bay is an example.

The rapidity of the rise of sea level was a major factor in the formation and maintenance of estuaries. Sedimentation could not keep pace with the rapidly rising sea that invaded numerous coastal basins. For the past few thousand years, however, the relative rate of infilling has been much greater than during the preceding several thousands of years. The rate of sea level rise has been slower, and within the past few hundred years the rate of sediment input has increased as a result of man's activities. It is, of course, the relative sea level rise—the rise relative to the sedimentation rate—that determines the geological lifetime of an estuary.

All modern estuaries then, are quite young geologically; certainly less than 15,000 years old. The relative youthfulness of many estuaries, particularly of drowned river valley estuaries like Chesapeake Bay, is indicated by their highly irregular, dendritic shorelines. As estuaries mature there is a progressive rectification or straightening of their shorelines; headlands are attacked by waves and current, and re-entrants in the coastline are filled by drifting sand. Once formed, estuaries are ephemeral features on a geologic time scale, being rapidly filled with sediments. Sediments are introduced not only by shore erosion, but also by rivers, by the wind, by the sea, and by biological activity. The sources are thus external, internal, and marginal. Typically, estuaries fill from their heads and their margins. An estuarine delta generally forms in the upper reaches of the estuary—near the new river mouth. The estuarine delta grows progressively seaward, extending the realm of the river and thereby expelling the intruding sea from the semi-enclosed coastal basin. Lateral accretion by marshes may also play a major role. As a result of these processes, the estuarine basin is converted back into a river valley. Finally, the river reaches the sea through a depositional plain and the transformation is complete.

While depositional rates in estuaries are naturally high, man's activities both within the estuarine zone itself, and throughout the drainage basin (sometimes hundreds of kilometers away) can greatly increase the sediment yields and the rates of filling, can alter the natural sedimentation patterns, and can shorten the geological lifetimes of estuaries—sometimes appreciably. More importantly, the indirect effects of increased inputs of sediments, particularly of fine-grained sediments, can degrade an estuary, or segments of it, to the extent that its useful biological and recreational lifetimes are cut drastically shorter than its geological lifetime—perhaps several orders of magnitude shorter.

It has been reported that when John Adams, a Democrat, was President, he swam in the upper Potomac at Washington, D.C. Lincoln, a Repub-

lican, not only did not swim in the upper Potomac, but remarked that the stench from it was sometimes so bad that on warm summer evenings when the wind was off the Potomac he had to flee the White House. This indicates either that the quality of the upper Potomac had been seriously degraded by man's activities over this period of about 60 years; or as a Republican friend of ours, H. H. Carter, points out, merely that "a Democrat will swim in anything."

ESTUARINE CIRCULATION AND SEDIMENTATION PATTERNS

Because of their characteristic circulation processes, estuaries are effective sediment traps. The tidal circulation is important in the formation of channels, tidal flats, and tidal deltas, but it is the net non-tidal circulation that is of primary importance in determining the rates and patterns of filling of most estuaries.

It is in the estuary where the mixing of fresh water from the land and salt water from the ocean produces dynamic conditions that lead to the eventual discharge of the river water to the ocean. The mixing may be due primarily to the action of the river, the wind, or the tide. There is a sequence of estuarine circulation types displaying different degrees of mixing of the fresh water and the sea water. The position that an estuary occupies in this sequence depends primarily upon the relative magnitudes of the riverflow and the tidal flow, and upon the geometry of the basin that contains the estuary. Changes in any of these factors may produce changes in the estuarine circulation pattern and may thereby alter the resulting sedimentation patterns. One end member of this sequence is the poorly mixed (highly stratified) salt-wedge estuary—that so-called Type A estuary. The other end member is the thoroughly mixed, sectionally homogeneous estuary—the Type D estuary. Two intermediate types which have been described are the partially mixed, Type B, estuary, and the vertically homogeneous, Type C, estuary.

Estuaries are actually continuously varying in their characteristics and may shift from type to type as conditions change. Also, at any given time, different circulation types may be observed within different segments of an estuary, depending on the relative magnitudes of the tidal flow and the freshwater flow, and upon the local geometry of the basin. The four types of estuarine circulation patterns are shown schematically in Fig. 2. In general, an estuary changes from Type A (Fig. 2A) to Type D (Fig. 2D) as the magnitude of the tidal flow increases relative to the riverflow and/or as the width of the basin increases relative to the depth.

The Salt-Wedge (Type A) Estuary

The Type A estuary, Fig. 2A, is a river-dominated estuary. It is also called a salt-wedge estuary because there is little mixing between the seawater and the fresh water, and the encroaching seawater is present as a wedge underlying the less dense, fresher river water. Salt-wedge estuaries occur where the ratio of width to depth is relatively small and the ratio of riverflow to tidal flow is relatively large. At locations upstream from the tip of the salt-wedge, the flow is downstream at all depths. Seaward of the tip of the wedge, the flow throughout the upper layer is still downstream at all times because of the dominance of the river over the tide. In the lower layer, the instantaneous flow may be upstream at all times, or it may reverse with the tide, but the net flow is upstream.

Fine suspended particles that are brought into the estuary by the river and settle into the lower layer are brought back upstream to the tip of the wedge by the slow net landward flow of the lower layer and accumulate in the vicinity of the tip of the wedge. This fluvial sediment may also be supplemented by fine particles from other sources. Heavier particles transported along the riverbed accumulate upstream of the wedge. The region surrounding the tip of the wedge, then, is a zone of rapid shoaling. The position of the tip of the salt-wedge is determined primarily by the freshwater discharge and the channel depth.

The Southwest Pass of the Mississippi River is a classic example of a salt-wedge estuary. The average flow through Southwest Pass is more than 5,100 m^3/sec (180,000 ft^3/sec), and peak flows may exceed 8,500 m^3/sec (300,000 ft^3/sec). The river completely dominates the circulation. The tidal range in the Gulf of Mexico is only about 36 cm (1.3 ft). The tip of the wedge migrates more than 235 km (126 n. miles) in response to changes in the discharge of the Mississippi. During periods of minimum flow, the tip may be about 40 km (22 n. miles) above New Orleans—nearly 235 km (126 n. miles) above the mouth of Southwest Pass. During periods of moderate flow, the tip of the wedge is located near the river's mouth, and the shoaling problem is so serious in this region that around-the-clock dredging is required to keep the navigation channel open.

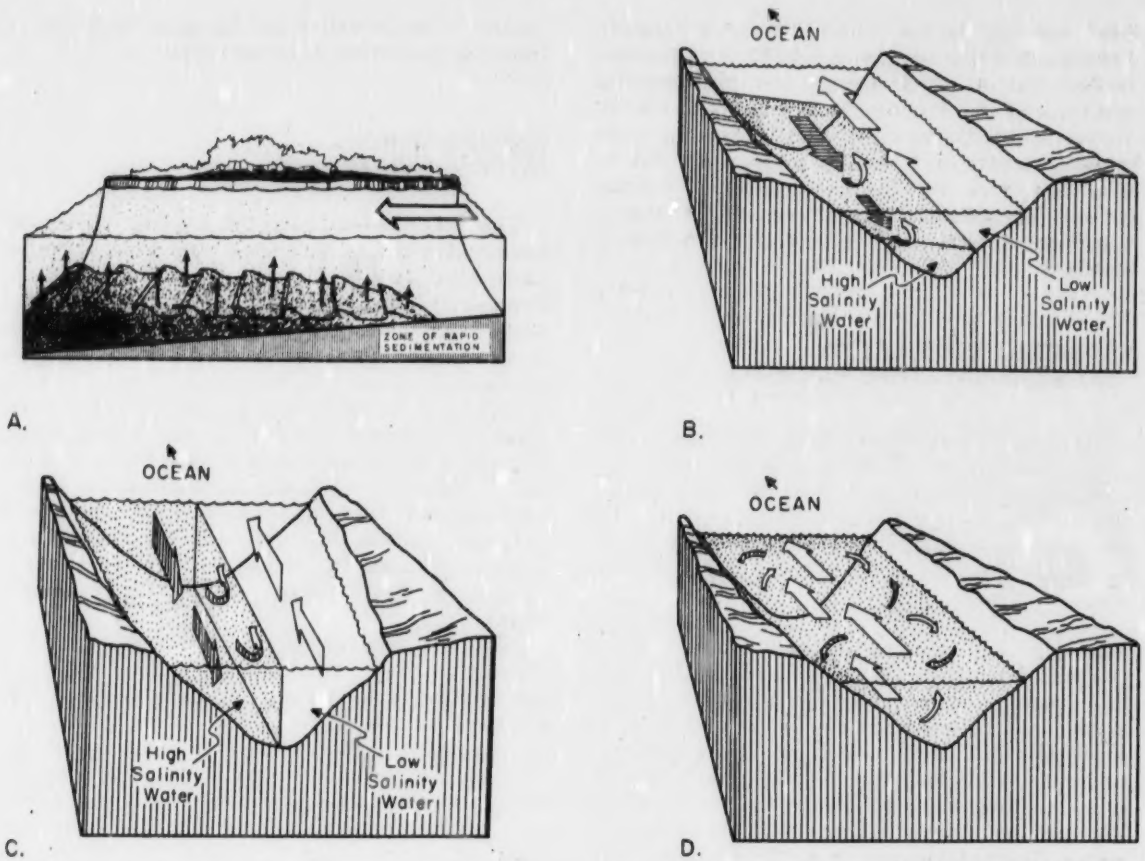

FIGURE 2.—Four distinct examples in the sequence of estuarine types. A. Type A estuary. B. Looking seaward in Type B estuary in N. Hemisphere. C. Looking seaward in Type C estuary in N. Hemisphere. D. Looking seaward in Type D estuary in N. Hemisphere.

The Partially Mixed (Type B) Estuary

If the tidal flow is increased relative to the river-flow so that the tide is sufficiently strong to prevent the river from dominating the circulation, the added turbulence provides the mechanism for erasing the salt-wedge. This occurs when the volume rate of flow up the estuary on a flood tide is on the order of 10 times the volume rate of inflow of fresh water from the river. There is both advection and turbulent mixing across the freshwater-saltwater interface. The sharp interface which separated the fresh water of the upper layer from the sea water of the lower layer in the salt-wedge estuary is replaced by a region of more gradual change in salinity. Such an estuary is called a partially mixed, Type B, estuary. The difference in salinity between top and bottom remains nearly the same over much of the length of the estuary. The Coriolis force—an apparent deflecting force caused by the earth's rotation—produces a slight lateral salinity gradient across the estuary. The boundary between the seaward-flowing upper and landward-flowing lower layers is slightly tilted. In the Northern Hemisphere, the upper layer is deeper and the flow slightly stronger to the right of an observer facing seaward. The lower layer is nearer the surface and its flow is slightly stronger to the left of the seaward-facing observer.

Fine suspended particles that settle into the lower layer are carried upstream by its net landward flow, leading to an accumulation of sediment on the bottom between the upstream and downstream limits of salt intrusion. Because of the mixing which is more intense than in a salt-wedge estuary, there is

generally an accumulation of fine suspended sediment in the landward reaches of the estuarine circulation regime. Such features, called "turbidity maxima," have been reported in the upper reaches of a large number of partially mixed estuaries throughout the world. These turbid zones characteristically begin in the estuary where a vertical gradient of salinity first appears and commonly extends downstream for 20–40 km (10–20 n. miles). Within a turbidity maximum the concentrations of suspended sediment and the turbidities are greater than either farther upstream in the source river or farther seaward in the estuary. Their formation has been attributed to the flocculation of the fluvial sediment, to the deflocculation of fluvial sediment, and to hydrodynamic processes. We believe that turbidity maxima are produced and maintained by physical processes—specifically the periodic resuspension of bottom sediments by tidal scour, and the estuarine circulation pattern—and that the importance ascribed to the role of flocculation in estuarine sedimentation is not supported by field evidence.

The most rapid shoaling in partially mixed estuaries normally is between the flood and ebb positions of the limit of sea salt intrusion. Rapid shoaling may also occur where the upstream flow of the lower layer is interrupted by entering tributaries, by abrupt changes in cross-sectional area, or by meandering or bifurcation of the channel. The Chesapeake Bay is a good example of a partially mixed estuary.

The Vertically Homogeneous (Type C) Estuary

If the role of the tide, relative to the river, is increased over that in the partially mixed estuary, the tidal mixing may be sufficiently intense to completely eradicate the vertical salinity gradient and produce a vertically homogeneous water column. The longitudinal salinity gradient still remains with the salinity increasing seaward. And, because of the Coriolis force, the lateral gradient in salinity also remains with the higher salinity water to the left of an observer facing seaward in the Northern Hemisphere. The boundary between the lower salinity water flowing seaward and the higher salinity water flowing up the estuary becomes more nearly vertical, and may intersect the water surface. In the Northern Hemisphere then, the net flow and sediment transport are generally upstream on the left side of the estuary facing seaward and downstream on the right side. Shoaling is generally most rapid near the upstream limit of sea salt, in regions of large cross-sectional area, adjacent to islands, and in channel bifurcations where the flow is interrupted. The wider reaches of the Delaware and Raritan (New Jersey) Bays are examples of vertically homogeneous estuaries.

The Sectionally Homogeneous (Type D) Estuary

If the tidal flow is increased even more so that it is very large relative to the riverflow, it may almost completely overwhelm the effect of the river. The tidal mixing may be so intense that not only is the vertical salinity gradient eradicated, but so also is the lateral gradient, producing a sectionally homogeneous estuary. The movement of water is essentially symmetrical about the main axis of the estuary with a slow net seaward flow at all depths. Truly sectionally homogeneous estuaries may not exist in nature. In estuaries that are approximately sectionally homogeneous, the most rapid sedimentation occurs in areas where the slow net seaward flow is interrupted by tributaries or obstacles. The Piscataqua estuary in New Hampshire appears to be nearly sectionally homogeneous, but observations in estuaries of this type are limited.

As pointed out previously, the position that an estuary occupies in this sequence of estuarine types depends primarily upon the relative magnitudes of the riverflow and the tidal flow, and upon the geometry of the basin. Relatively subtle changes in any of these factors may produce changes in the estuarine circulation pattern and thereby alter the resulting sedimentation patterns. In general, an estuary's sediment trapping efficiency is increased as the riverflow increases relative to the tidal flow, or as the depth increases. Most of the fluvial sediment is generally introduced into an estuary when the riverflow is high, when its trapping efficiency is greatest. When the riverflow subsides and the relative importance of the tidal flow increases, the estuary shifts in its circulation pattern toward one of greater mixing. During these more prolonged periods of low to moderate riverflow the sediment is redistributed.

ALTERATION OF PREVAILING SEDIMENTARY PROCESSES

Sources

Although sediment in estuaries comes from many sources—including the erosion of the margins of the estuarine basins, and the beaches and sea floor outside the estuary mouths—the sources most affected by the hand of man are the rivers that carry sediment from upland areas into the estuaries. Our

discussion will focus mainly on the sediment loads of rivers, which are increased by such activities as farming, mining, and urbanization; and which are decreased by reservoirs and other protective works.

MAN'S ACTIVITIES THAT INCREASE RIVER SEDIMENT LOADS

Ever since the first European settlers landed, man has affected the amount of sediment in streams draining North America. The influence of man on sedimentation is especially well documented in the Chesapeake Bay region, where clearing of forests and wasteful farming practices (especially those used in raising tobacco) contributed enormous loads of sediment to the rivers. Clear streams became muddy and once relatively deep harbors at the heads of a number of the tributaries were filled with sediment. The Potomac River, whose waters were already somewhat turbid but which were still suitable for municipal use in 1853, had become so muddy by 1905 that the city of Washington had to install its first filtration plant. A comparison of the 1792 and 1947 shorelines of the upper Potomac (Fig. 3) shows that large areas of the Potomac near Washington have been filled with sediments stripped from farmland farther upstream. The Lincoln and Jefferson Memorials now stand on what was described in 1711 as a harbor suitable for great merchant vessels. Even today, an average of about 2 million m^3 (2.6 million yds^3) of sediment is deposited every year near the head of tide in the Potomac; not all of this sediment is the result of agriculture, as we shall see. There are other former seaport towns on the western shores of Chesapeake Bay where decaying docking facilities are now separated from navigable water by several miles of sediment-filled lowland.

Streams that drain modern day farmlands in many of the mid-Atlantic states carry about 10 times as much sediment as streams that drain equivalent areas of forest land. And this relation is by no means unique. In the Coastal Plain of northern Mississippi, sediment yields from cultivated lands are 10 to 100 times the yields from equivalent areas of forested lands. In two other areas where studies have been made—the Tobacco River Valley of Michigan and the Willamette Valley of Oregon—streams draining farmland carry two to four times as much sediment as streams draining equal areas of forested land.

Mining is another activity that has increased the sediment loads of rivers that flow into some estuaries. San Francisco Bay, for example, contains nearly a billion cubic meters of sediment washed from the Sierra Nevada during the 30-odd years of intensive hydraulic mining for gold. Even after the hydraulic processing was stopped in 1884, the mining debris continued to choke the valleys of the Sacramento River and some of its tributaries for many decades. Gradually, over the years, the debris has been moved downriver to be deposited more permanently in the marshes and shallower areas around San Francisco Bay. The mining debris that was released in only three decades is more than the total sediment from all other sources (including farmland) that the Sacramento River has carried in the twelve-and-a-half decades since 1850. It has been shown that this sediment had an important effect on the bay; the tidal prism was decreased, and the flushing regime significantly changed.

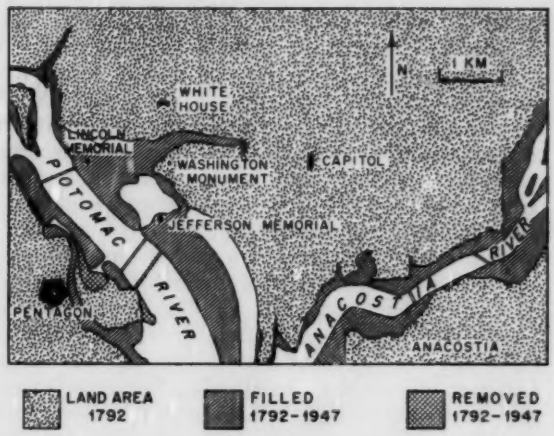

FIGURE 3.—Accumulation of sediment at Washington, D.C., near the head of tide in the Potomac and Anacostia Rivers, between 1792–1947.

Urbanization is the most recent of man's activities to contribute large amounts of sediment to streams. Sediment loads derived from land being cleared or filled for the building of houses, roads, and other facilities are best documented in the area between Washington, D.C. and Baltimore, Md. During periods when housing developments, shopping centers, and highways are being built, the soil is disturbed and left exposed to wind and rain. The concentration of sediment in storm runoff from construction sites is a 100 to 1,000 times what it would be if the soil had been left in its natural vegetated state. Even though the soil is left exposed to erosion of this intensity for only a short time—a few years at most—the amount of land cleared for

new housing and ancillary uses in the Washington-Baltimore area has been so great in recent years that the contribution of sediment is significantly large. Harold Guy of the U.S. Geological Survey has estimated that the Potomac River receives about a million tons of sediment per year from streams that drain the metropolitan Washington area. This is about the same amount of sediment that the Potomac River brings into the Washington area from all its other upland sources.

Another of man's activities that increases the sedimentation rates of estuaries is the disposal of dissolved phosphorus, nitrogen, and other plant nutrients into rivers and estuaries. Municipal sewage effluents, including effluents that have received secondary treatment—the highest degree of conventional treatment—contain high concentrations of nutrients. In some areas, agricultural runoff from fertilized croplands and animal feedlots also contributes nutrients to river waters and estuaries. These nutrients promote the growth of diatoms and other microscopic plants (phytoplankton) both in the rivers and in the estuaries that the rivers flow into. The mineral structures formed by many of these organisms persist after the organisms die and become part of the sediment loads of the rivers and the sedimentary deposits of the estuaries. The Army Corps of Engineers estimates, for example, that the diatom frustules produced in the Delaware River and Delaware Bay contribute about the same amount of sediment (a million-and-a-half tons per year) to the Delaware estuary as all other upland river sources. The effects of nutrient loading from municipal wastes on primary productivity are readily observable in the Potomac estuary, in Baltimore Harbor and the Back River estuary (Maryland), in Raritan Bay, in the Arthur Kill estuary, in the Hudson estuary, in the Delaware estuary, in San Francisco Bay, and in many other estuaries around the country. Stimulation of plant growth by nutrient-enriched runoff from agricultural areas is apparent in the upper Chesapeake Bay, the estuary of the Susquehanna River.

Man's Activities That Decrease River Sediment Loads

Reservoirs probably cause the most significant interruptions in the natural movement of sediment to estuaries by rivers. Reservoirs are built on rivers for a number of purposes: for hydroelectric power, for flood control, for water supply, and for recreation. Regardless of their purpose, reservoirs share in common the ability to trap sediment. Even small reservoirs can trap significant proportions of river sediment. For example, a reservoir that can hold only one percent of the annual inflow of river water is capable of trapping nearly half the river's total sediment load. A reservoir whose capacity is 10 percent of the annual river water inflow can trap about 85 percent of the incoming sediment. Although a river will tend to erode its own bed downstream of a reservoir to partly compensate for the sediment it has lost, the net effect of the reservoir is to decrease the overall amount of sediment carried by the river. In the larger river basins of Georgia and the Carolinas, the sediment loads delivered to the estuaries are now something like one-third of what they were about 1910, mainly because of the large number of reservoirs that have been built since then for hydroelectric power and, to a lesser extent, for flood control.

On some rivers, settling basins and reservoirs have been built specifically as sediment traps to improve the quality of water farther downstream. In 1951, three desilting basins were constructed on the Schuylkill River of Pennsylvania to remove the excessive sediment that resulted from anthracite coal mining in the upper river basin. The basins are dredged every few years, and the dredged material is placed far enough from the river to be out of reach of floods. As a result of these basins, the sediment load carried by the Schuylkill into the Delaware estuary has been reduced from nearly a million tons per year to about 200,000 tons per year.

Net Effect of Man's Activities on Sources of Sediment

The net effect of man's activities has no doubt been an increase in the sediment supplied to most of the estuaries of the United States, but we cannot say by how much. Although reservoirs and other controls have reduced the sediment in rivers in recent years, they have only partly offset the influences that caused the increases in the first place.

Added to this is the fact that sediment takes decades to move through a river system. Much of the sediments released by past mistakes—such as by poor mining practices and by poor soil conservation practices associated with agriculture—are still in the river valleys in transit storage between their sources and the estuaries. Even if the active supply of sediment to rivers were completely checked today, many decades would pass before the sediment loads would drop to their natural, pre-colonial, levels.

CONTROL OF RIVER SEDIMENT INPUT

The ultimate method of controlling the sediment that rivers contribute to estuaries is to control erosion at the source. The possibility of complete control, however, is remote. Erosion is basically a natural phenomenon. All land, whether in its natural state or altered by man's activities, yields a certain amount of sediment. Because the natural processes of erosion are less subject to control than are man's influences on these processes, perhaps the best that one can hope for is to keep erosion down to its natural level. But even this is probably a vain hope. In spite of the marked reduction that conservation measures have caused in soil erosion since they began to be applied in earnest over 30 years ago, cultivated farmland in the eastern United States, for example, continues to yield sediment at about 10 times the rate of equivalent areas of forested land. In places where former croplands and grazing lands have been replanted in forests and grasses, sediment yields have been considerably reduced. Although it is true that as long as men cultivate land, there seems to be little hope of reducing sediment yields to their natural rates—rates typical of heavily vegetated lands—much more effort should be directed at reducing sediment yields through appropriate soil conservation practices. If these controls are enforced not only for agriculture, but also for strip mining, urbanization, and highway construction, significant reductions in sediment inputs to estuaries will result. These reductions will, within a period of decades, be manifested in reductions in the dredging activity required to maintain many shipping channels; and may result in improvement in water quality of the estuarine zone, particularly if nutrient inputs are decreased.

ROUTES AND RATES OF TRANSPORT

Once sediment reaches an estuary, it may move directly to a site where it will remain permanently, but it is more likely to be deposited in a series of temporary storage areas or "parking lots" before coming to its final resting place. Although we have some idea of the kinds of places where sediment is most likely to eventually accumulate in estuaries, we are generally unable to predict the detailed route that sediment will follow between the point where it enters the estuary and the place where it finally comes to rest. Furthermore, we know little about how often sediment moves—whether it moves a short distance every day, or moves mainly during short but severe events such as storms and floods. We suspect that infrequent severe events are more important in delivering sediment to the estuary in the first place, but that the slower day-to-day processes are more important in redistributing sediment from one part of an estuary to another to determine the final depositional patterns. In upper San Francisco Bay, for example, the sediment brought in by the Sacramento River during the rainy winter months is initially deposited in broad shallow areas of the estuary. During the dry summer months the daily breezes that blow across the bay stir up the shallow waters and resuspend the sediments blanketing the shoal areas. The tidal currents transport this material to deeper areas, mostly farther up the bay. The deeper areas, in and near Mare Island Strait, are the location of the most intensive dredging of navigation channels in San Francisco Bay. About two million cubic meters, or about a third of all the sediment dredged in the entire San Francisco Bay system, are removed every year to maintain adequate channels into and within the Mare Island Naval Shipyard.

If we have only a limited knowledge of the routes of transport within the estuary, we know even less about the rates of transport. We have some measurements of the rates at which sediment is supplied to the estuary from selected sources, mostly rivers. And, we have some knowledge of the rate at which some of the sediment accumulates in specific parts of estuaries, particularly in the dredged navigation channels. But we have only a limited picture of the rates of input from other sources and the rates of accumulation at other less obvious places, and a particularly limited picture of the rates at which a given particle of sediment might be expected to move from one part of the estuary to another on its way to a permanent resting place.

Patterns of Deposition

The pattern of deposition of sediment in an estuary is determined mainly by the non-tidal circulation patterns of the water. As pointed out previously, an estuary's net circulation pattern is determined primarily by the relative magnitudes of the river and tidal flows, and by the geometry of the estuarine basin. The circulation pattern can be altered, sometimes drastically, by changes in any of these factors.

TRAINING WORKS

Training works such as jetties and dikes are built for the expressed purpose of changing the pattern of flow and deposition in estuaries: specifically, to

discourage the deposition of sediment where it is not wanted, or to facilitate its deposition in other places. The deposition of sediment is discouraged by channeling flows to increase their velocity and scouring potential. Deposition is encouraged by providing quiescent areas where suspended particles can settle to the bottom.

Although in theory training works should be an efficient means of controlling sediment, in practice their results are often difficult to predict. Works constructed in the early years of this century along the main shipping channel in Liverpool Bay in England, for example, were successful in increasing the velocities and the depths in the channel. However, they caused an unexpectedly rapid increase in sedimentation in the areas of the bay outside the channel as well as in the tributary estuary of the Mersey River.

DREDGING

Since problems associated with dredging are discussed at length in several other papers in this volume, our comments will be limited. Dredging of navigation channels is the most pervasive of man's activities in estuaries that affect the circulation of water, and consequently, the pattern of deposition of sediment. In many estuaries, dredging seriously disrupts the natural equilibrium that formerly existed between river inflow, tidal exchange, sediment supply, and the configuration of the estuary floor. The response to dredging is frequently to "heal" the disruption by filling the dredged channel with sediment.

If left to itself, the healing might proceed in the following way. Suppose we have an estuary where the sediment inflow and the bottom geometry are in some kind of steady-state balance with respect to each other. This might be a large estuary, such as Delaware Bay, that is slowly and steadily being filled with sediment, mainly in its upper reaches; or it may be a narrow estuary, such as the Savannah River between Georgia and South Carolina, that flows in a river-size channel through sediment-filled lowlands to the sea. When a deep channel is dredged in such an estuary, it allows salt water to penetrate farther inland than formerly and it shifts the nodal point of the upstream flowing seawater farther up the estuary. This nodal point becomes the locus of most rapid sedimentation and remains so until the channel at that point is filled with sediment. When that part of the channel is filled and the salt water can no longer penetrate that far inland, the nodal point is progressively shifted seaward and another part of the channel is filled. This process continues until the entire navigation channel is healed—provided that enough sediment and time are available. If the navigation channel is dredged repeatedly, as are most channels where the supply of sediment is heavy, the sediment continues to accumulate at or near the first nodal point which continues to be the location of maximum dredging effort in the estuary. The maintenance of navigation channels in many estuaries, therefore, is a battle between man's efforts to disrupt a pre-existing state of equilibrium, and the estuary's tendency to restore that equilibrium.

A major problem in dredging is the disposal of the dredged material (spoil). In many cases, spoil is dumped in places where sediment of that texture would not have accumulated naturally, or at least not nearly as rapidly in the natural course of events as in spoiling. This applies to disposal sites both inside and outside of estuaries.

Spoil is commonly dumped inside the estuary, sometimes directly alongside the channel. The spoil may remain where it is dumped, especially if it is dumped in deep spots out of reach of strong currents. Often, however, dredge spoil returns to the channel. In recent years, according to estimates made by the U.S. Army Corps of Engineers, about half the sediment dredged from the navigation channels in Charleston Harbor and San Francisco Bay is material that has already been dredged at least once before and has made its way back into the channels from the place where it was dumped.

In some estuaries, spoil is dumped on fringing land areas. A principal advantage is that these areas can be diked to prevent the return of the spoil to the estuary. The main disadvantage is that the marginal areas are often salt marshes that are valued for their role in the protection and production of fish and other forms of estuarine life. Dumping spoil on these areas usually destroys their original plant and animal communities.

Spoil is also taken by barge or hopper dredge and dumped in the ocean outside estuaries. In 1968, for example, about 50 million tons of dredged material was dumped in ocean waters off the coast of the United States. In many ocean areas, such as off New York city where some 7 million tons of spoil are dumped every year, the spoil is a markedly different type of sediment from the natural bottom material and it is introduced at a rate many times greater than the natural rate of local sediment input to the ocean. This is perhaps man's greatest alteration of the pattern of deposition—taking material that was destined by nature to be deposited in estuaries and dumping it at sea.

Modification of Prevailing Sedimentation Processes By Engineering Projects: A Mistake and A "Success"

CHARLESTON HARBOR

Charleston Harbor, one of the finest natural harbors on the Atlantic seaboard, has served the needs of the region since the town was settled in 1670. It is an interesting example of an estuary whose circulation and sedimentation were markedly altered by changing the freshwater input to the estuary. The Charleston Harbor estuary receives freshwater inflow from the Ashley, Cooper, and Wando Rivers. The mouth of the estuary is restricted, and entrance from the Atlantic Ocean is gained through a single, jettied-channel. Prior to 1942, the freshwater input was very small, averaging less than 20 m^3/sec (700 ft^3/sec), and the harbor was somewhere between a vertically homogeneous and sectionally homogeneous estuary. Fine-grained sediment was moved slowly through the estuary to the ocean, and little dredging was required. Maintenance dredging to keep the main channel at a depth of 9 m was only about 60,000 m^3/yr (80,000 yds^3/yr) at a cost of about $11,600/yr.

In late 1941, a hydroelectric dam was completed which diverted most of the flow of the nearby Santee River, the largest river on the south Atlantic seaboard, into the upper Cooper River which flows into Charleston Harbor. The average freshwater input to the harbor rose from less than 20 m^3/sec (700 ft^3/sec) to more than 400 m^3/sec (14,000 ft^3/sec). The inflow of fluvial sediment was increased by about a factor of four. More importantly, the marked increase in the freshwater discharge shifted the circulation pattern in the harbor from a well-mixed estuary to a two-layered circulation pattern characteristic of a partially-mixed (Type B) estuary. Fine sedimentary particles which would previously have been carried completely through the estuary to the ocean were now entrapped in the estuary by the net upstream flow of the lower layer and accumulated in the inner harbor—in the upper reaches of the non-tidal estuarine circulation regime. Shoaling became a serious problem. Dredging required to maintain the inner harbor channel jumped to an average of 1.8 million m^3/yr (2.3 million yds^3/yr) at an average cost of about $380,000/yr during the 9 year period from 1944 to 1952. More recently, dredging has averaged about 7.5 million m^3/yr (10 million yds^3/yr).

Nearly half of the currently dredged material represents older dredged spoil that has returned to the channel. Another 10 percent or so of the new spoil is due to the deepening of the main navigation channel from 9.1 to 10.7 m (30 to 35 ft) between 1941 and 1943. The major factor in the increased shoaling rate was the change in estuarine circulation produced by the diversion of water from the Santee River into the harbor. This was conclusively demonstrated by hydraulic model studies.

The shoaling problem has become so difficult and expensive to control that plans are well underway for rediversion of the Santee back to its original channel.

DELAWARE BAY

Delaware Bay has also served maritime commerce since colonial times, providing access between the sea and such cities as Philadelphia and Trenton. In recent years some fairly successful measures have been taken to control sediment, both in the inflowing rivers and in the bay itself. The desilting works in the Schuylkill River need no further discussion here except to point out that they have resulted in a fivefold decrease in the sediment brought by the Schuylkill to the upper estuary at Philadelphia.

Within the Delaware estuary, the Corps of Engineers has been able to decrease the amount of dredge spoil that has returned to the navigation channels. Before 1954, when spoil was dumped overboard in the Delaware estuary 15 to 20 million m^3 (20 to 26 million yds^3) of sediment were dredged in an average year, and the navigation channel could not always be maintained at its specified depth. Beginning in 1954, all dredge spoil was placed in diked areas to prevent its return to the channels. Since then, only about 6 million m^3 (8 million yds^3) of sediment are dredged every year, and the navigation channels are consistently deeper. Although this is one of the more successful instances of coping with estuarine sedimentation, it is only a temporary expedient in the long run. Peripheral lands for spoil disposal are becoming scarcer and more costly because of competing demands such as development or conservation, and the end of available land for spoil disposal around the fringes of the Delaware estuary is already in sight.

The Effects of Sediments on the Biota and on the Aesthetics of the Estuarine Environment

Clearly, man has affected the input of sediments to estuaries by land-use practices throughout their drainage basins, by the construction of dams and

reservoirs on tributary rivers, by diversion of rivers, and by engineering projects to control shore erosion of the margins of estuaries. He has also affected the distribution patterns of sediments within estuaries, both in the water column (suspended sediments) and on the bottom (deposited sediments), by changing the estuarine circulation patterns either through alteration of the freshwater inputs, or through modification of their geometry by dredging or by other engineering projects. Man's impact on depositional patterns has already been described briefly in the previous section. In addition to the obvious effects of shoalings on basin geometry and therefore on circulation, and on the geological lifetimes of estuaries, changes of the rate of sedimentation and of the character of the sedimentary material can have significant effects on organisms, particularly the animals that live on the bottom. Fine-grained sediments may also affect the chemical character of the interstitial water and, when resuspended by waves and currents, that of the overlying waters.

EFFECTS ON THE BIOTA

Dredging and the disposal of dredged materials have generated a great deal of concern, discussion, and speculation about the impacts of such activities on the quality of the estuarine environment. During active dredging and spoiling there are increases in the concentrations of suspended sediment. Substantial increases—increases of more than a few hundred mg/l—are generally local, restricted to an area within a few hundred meters of the activity, and any biological or aesthetic effects of these increased turbidities are not persistent.

Dredging can, of course, alter the estuarine circulation pattern and, in doing so, also change both the general sediment distribution patterns and the concentrations of suspended sediment. Changes in these factors can persist after dredging and spoiling have been completed.

Increases in the concentrations of suspended sediment above some threshold level that result from any activity can have significant environmental effects—on aesthetics, on water quality, and on the biota. The available literature indicates, however, that direct effects of suspended sediment on most estuarine organisms of the higher trophic levels occur only at relatively high concentrations, concentrations greater than 500 mg/l, and generally greater than 1,000 mg/l. Such concentrations are rare in most estuaries, even during dredging and spoiling activities except at, or very near, the source. Even in the immediate vicinity of dredging activity, the increased suspended sediment concentrations may not be lethal to important organisms of the higher trophic levels. Studies of caged fish and crustaceans placed within 8 to 15 meters of active dredges and overboard spoil discharges failed to produce any evidence of increased mortality or damage to gill epithelium compared to control organisms.

It has also been reported that there was no increase in the mortality of oysters adjacent to dredging operations in the intercoastal waterway near Charleston, S.C. The same investigators also found that oysters could survive even when suspended directly in the turbid discharge, and that the organisms died only when they were actually buried. Other investigations indicated that oysters decrease their pumping rates when subjected to relatively high concentrations of suspended sediment. It has been reported that a concentration of suspended silt of only 100 mg/l reduces the pumping rate of adult oysters by about 50 percent. If the pumping rate were reduced below some critical threshold for an extended period, the oyster would obviously die from starvation. It is unlikely that this would happen as a result of dredging activity. Furthermore, concentrations greater than 100 mg/l occur naturally over many productive oyster bars whenever bottom sediments are resuspended by normal tidal currents. These periodic increases of suspended sediment do not appear to seriously affect growth rates.

Sublethal effects of chronic exposure to moderate excess concentrations of suspended sediment—concentrations above those that would occur naturally—have not been convincingly documented for any estuarine species. Such effects will be difficult to establish unequivocally. One would anticipate that sensitivity to suspended sediment would be a function not only of species, but of life stage, and of other environmental stresses.

Increases in the concentration of suspended sediment that are large enough to markedly change the visibility of the waters of segments of an estuary can produce shifts in the fish population. Since game fish feed by sight, some minimum visibility is required for successful feeding. If visibility falls below this threshold, fish such as carp which feed in a vacuum-cleaner fashion are favored. This probably occurs only when concentrations of fine suspended sediment exceed several hundreds of mg/l. Visibility is a function not only of the concentration of total suspended solids, but also of their size distribution and composition.

The disposal of dredged materials generally results in the initial destruction of many, perhaps most, of

the bottom dwelling organisms (benthos) at the disposal site through burial and smothering. It has been documented in a number of estuaries, however, that the spoil is recolonized relatively rapidly by organisms from surrounding areas except when the spoil differs markedly in texture from the host sediments. Studies of overboard disposal sites in the upper and lower Chesapeake Bay showed that within one-and-one-half years the population density and species diversity of the spoil areas could not be distinguished from those of surrounding areas. In the upper Chesapeake Bay recovery of the channel—the dredged area—was not complete, but in the lower bay complete recovery of both the dredged and spoil areas was documented. Where marked textural changes result from the dredging or spoiling activity, recolonization may be limited. The dredged canals of Boca Ciega Bay, Fla., are examples.

If dredging or spoiling produce substantial changes in the depth distribution of an estuary, or segments of it, significant changes may occur in habitat space and therefore in the distribution of organisms. Areas of the bottom can be removed from the euphotic zone by dredging, and areas can be built-up by spoiling from a relatively deep position into the surface layer where they are subjected to stirring by currents and waves. Clearly such alterations are not necessary consequences of dredging and spoiling.

The magnitude of the impact of dredging and spoiling is also a function of the time of year they are done. These activities should be scheduled when there will be the least probable impact on the most "important" indigenous species. Generally, for any given species the early life history stages are more sensitive to environmental stresses than later stages.

Studies indicate that substantial dredging and spoiling projects can be carried out in estuaries without any gross biological effects or any persistent aesthetic degradation. Any chronic biological effects that might arise either from exposure of organisms to spoil and associated contaminants for long periods, or from exposure to relatively subtle, but persistent, changes of the physico-chemico milieu have not been documented. Much of the research that has been done and is still being done to determine the effects of dredging and spoil disposal is ill conceived and will not provide answers to the pertinent questions.

Effects on Water Quality and Aesthetics

Fine-grained suspended sediment can affect the distribution of dissolved oxygen in estuarine waters both directly and indirectly. The oxygen demand of organic-rich sediments may produce a sag in the oxygen distribution. It has been reported that in the Arthur Kill, for example, when dredged spoil was resuspended oxygen levels were reduced from 16 to 83 percent below their average levels. Other investigators reported that when surface sediments from Wassaw Sound, Ga., were suspended in the estuarine water, they were capable of removing "533 times their own volume of oxygen from the water." No such effect was observed in the upper Chesapeake Bay, and studies of Louisiana marshes did not demonstrate any significant oxygen depletion as a result of dredging activities. Since the concentration of suspended sediment affects the transparency of water, increases in suspended sediment levels decrease the depth of the euphotic zone and therefore the production of oxygen by phytoplankton.

Increased suspended sediment concentrations may also affect the production of oxygen by rooted aquatic plants. Areas of the bottom formerly within the euphotic zone can be removed from it as a result of man's activities. Prior to about 1920 much of the bottom of the upper Potomac outside of the channel was covered with a dense growth of rooted plants. During the 1920's this vegetation almost completely disappeared and lower oxygen levels were reported in this area. The effects of the disappearance of these plants on the distribution of dissolved oxygen were confounded by the effects of other significant environmental changes on oxygen levels.

Fine sedimentary particles can act as both a source and a sink for nutrients and other constituents. Nutrients may be sorbed onto fine-grained particles, or desorbed from them depending upon a variety of physico-chemico conditions. These include salinity, pH, temperature, the chemical composition of the particles, and the concentrations of nutrients in the water. The mechanisms that control these exchange processes are poorly understood, and should be investigated.

It is well known that fine-grained particles concentrate a variety of pollutants, including: petroleum byproducts, heavy metals, pesticides, and some radionuclides. In the water column the bulk of each of these contaminants is usually associated with fine suspended particles, and therefore the distribution, transportation and accumulation of these substances are determined primarily by the suspended sediment dispersal systems. Filter-feeding organisms which ingest these particles and associated contaminants agglomerate the smaller particles into larger composite particles in their feces and pseudofeces thereby providing the contaminants in a more concentrated form to deposit feeders. Laboratory experiments have demonstrated the ability of oysters

to concentrate DDT in their pseudo-feces. Increases in the concentration of DDT and other pesticides in detritus particles of fine-grained bottom sediment of estuaries of up to 100,000 times those in the overlying waters have been reported. These residues can sometimes be transferred to detritus feeding organisms. Increases in the concentration of contaminants at each trophic level are well documented for radioactive isotopes and some pesticides. This phenomenon has been referred to as "biological magnification."

Fine sediments can also serve as a temporary sink for radioactive contaminants. It has been shown, for example, that ^{65}Zn may be held by fine-grained sediments for months with a continual low level release to the interstitial and overlying waters.

The effects of fine-grained particles and their associated contaminants on the composition of both the interstitial and overlying waters, and on the biota are poorly understood. This is an area that should receive considerable attention. From the standpoint of dredging, it is particularly important. Appropriate standards for permissible levels of contaminants in spoil should be based, not on the total concentration of each contaminant, but on the concentration that is available for biological uptake—the concentration of the reactive fraction. While standards based on totals are safe they place undue restrictions on the disposal of dredged materials. It is becoming clear that fine-grained particles play a significant role in determining the quality of the estuarine environment, and the composition of its biota.

Increases in the levels of suspended particulate matter can also have a significant aesthetic effect. Above some threshold level, suspended matter is aesthetically displeasing and inhibits recreational use. This level is a function not only of the total concentration, but also of the size distribution and the composition of the suspended material. A concentration of 100 mg/l of fine quartz sand does not have the same effect on water color and transparency as does the same concentration of organic-rich silt and clay. Individuals also have different aesthetic thresholds.

SOME RECOMMENDATIONS FOR FURTHER STUDY

Some of the types of studies we feel must be done if we are to understand how estuaries operate sedimentologically; if we are to be able to predict the consequences of manmade alterations of the prevailing sedimentary processes; and if we are to manage estuaries for the greatest use of man, are described below.

Sources of Sediment to Estuaries

One of our principal needs in understanding the sources of sediment brought to estuaries is for more complete data on the sediment loads carried by rivers—the principal source of sediments to most estuaries. In less than half of the estuaries of the country do we have any kind of regular measurement of the input of river sediment. Furthermore, the records we do have are mostly too short. Only a few river sediment stations have been in operation long enough to have documented the extreme events that are so important in the introduction of sediment: events such as the hurricane flood of August 1955 when the Delaware River carried more sediment past Trenton in two days than in all five years combined in the mid-1960's drought; or the three days in December 1964 when the Eel River in northern California transported more sediment than in the preceding eight years; or the week following Tropical Storm Agnes in June 1972 when the Susquehanna discharged 20–25 times as much sediment as during the previous year. Events of this magnitude occur only rarely—a few times a century at most—but their importance to estuarine sedimentation is so great that programs should be designed to record their effects when and where they do occur.

Daily sampling stations should be established on the lower reaches of all major rivers—upstream from the landward limit of measurable sea salt intrusion—to measure the inputs to estuaries of water, sediment, nutrients, and other substances. These stations should be permanently maintained to catch the large events, and permit an assessment of their relative importance. In addition, a funding mechanism should be developed to support research of the effects of events on the estuarine environment.

We also need to further our understanding of sources of estuarine sediments other than rivers. In a recent study of the sources of shoaling material in the navigation channels of the Delaware estuary, for example, the U.S. Army Corps of Engineers estimated that only one-fourth of the shoaling material could be accounted for by present day river sources. The remaining three-fourths was attributed to erosion of the bed and banks of the estuary, diatoms produced in the estuary in response to an excess supply of nutrients, and other sources (some of which could not be identified). It has been suggested that shore erosion is the principal source of sediment to the middle and lower reaches of the Chesapeake

Bay estuary. These sources deserve more of our attention so that we can identify them more accurately, assess the rates at which they add sediment to the estuaries, and find out to what degree they are subject to manipulation and control by man.

Routes and Rates of Sediment Transport

Tracers offer a promising approach to studying the routes and rates of sediment movement. Tracers such as fluorescent particles can be added to the sediment, and the sediment can be sampled repeatedly to determine the routes and rates of sediment movement; or one can make opportunistic use of distinctive contaminants, such as radioactive isotopes or heavy metals, that are dumped into estuaries either intentionally or inadvertently. These compounds sometimes can be used as labels to follow sediments from known sources to sites of deposition. Releases from nuclear power plants should be investigated as possible tracers. An attempt should be made to assess the impact of man on the prevailing sedimentary processes. Such an assessment would have to come primarily from an examination of the sedimentary record.

Patterns of Sediment Accumulation

In the past we have relied mainly on dredging records as a measure of sediment accumulation, but they tell us little about how sediments accumulate in the large areas of estuaries that lie outside the dredged channels. For some estuaries, modern day navigation charts have been compared with older ones (some dating back to the mid-1800's) to estimate the accumulation of sediment. Because the charts are already available, a systematic comparison of old and recent survey sheets could be made for most estuaries of the country at relatively little expense. Some newer techniques can also be applied—particularly those techniques that use the decay rate of naturally radioactive material to measure the age of sediment and how long ago or how rapidly it may have accumulated. An effort should be made to refine those radiometric dating techniques that are particularly applicable to estuarine deposits, and to apply the techniques to a variety of estuarine systems. The two methods that have the greatest promise are Pb^{210} which has a useful range of 10 to 100 years and C^{14} which can be used to date events that occurred in the past 1,000 to 10,000 years.

Another difficult aspect of the sediment budget of most estuaries is the question: on a net basis, does more sediment move out of the estuary into the sea than moves into the estuary from the sea? We know that sediment escapes from estuaries on outgoing tides, and we know that sediment is moved into estuaries from the sea floor on incoming tides; but we do not know enough about the quantity or kind of sediment that moves either way to be able to say whether, on balance, more moves out than in. Here again, well-designed tracer studies might be useful.

An estuary's sedimentary deposits contain the history of that environment, and it is only through the examination of this sedimentary record that one can assess the impact of man on the distributions of both naturally occurring substances and of man-made pollutants, such as PBCs (polychlorinated biphenyls) and pesticides. Naturally occurring substances include not only innocuous sedimentary particles, but also some pollutants; pollutants such as heavy metals which are present in the earth's crust and are carried into the estuarine environment both in solution and adsorbed to fine suspended particles by rivers and streams. Heavy metals are, of course, also introduced into the environment as a result of man's activities.

The sedimentary record also contains the most reliable information of the frequency of natural catastrophic events such as floods, droughts, and hurricanes that have occurred during the past several thousand years. The importance of episodes in the development of estuaries has not been well documented because of the infrequency of such events and the difficulty of sampling during most storms and floods.

Model Studies

Physical and mathematical models can provide valuable insight into a variety of sedimentary processes. They are not, however, a panacea for all estuarine sedimentation problems, and are only as good as the prototype data and theoretical assumptions on which they are based. Perhaps the greatest need is for more attention to be directed at the formulation of conceptual models of estuarine sedimentation. Conceptual models should, in any case, precede the construction of mathematical or physical models.

Characterization of Fine-Grained Sediments

Appropriate field and laboratory studies should be conducted to characterize the chemical and

mineralogic nature, and the reactivity of the fine-grained, carbon-rich particles. It is clear that fine-grained particles can play a major role in determining the quality of coastal waters, and the distribution of organisms. These studies should also include investigations that would lead to the establishment of meaningful diagnostic standards for the disposal of dredged materials. While the present standards used by the EPA to characterize dredged materials were intended to be environmentally conservative they may be unduly restrictive with respect to the designated parameters, while they ignore a large number of important contaminants such as PCBs, pesticides, and others. In any event, they are clearly not based on sound scientific evidence. Standards for dredged materials should not be based on the total concentrations of contaminants, but rather they should reflect the total masses of contaminants that are available for biological uptake. These masses are the concentrations of the reactive fractions of these contaminants—the fractions available for biological uptake—times the total mass of dredged material. Even with such standards, decisions on dredging and spoil disposal should be based on the physical, chemical, biological, and geological characteristics of the particular estuary. The uniform application of Federal standards has little merit other than simplicity of enforcement.

We know far too little about the effects of sediment-borne contaminants on estuarine life. We need an extensive series of laboratory experiments to test the effects of a variety of contaminants on different organisms. It is particularly important that these experiments simulate field conditions; too many of the experimental results we already have cannot be extrapolated beyond the laboratory. Only after such a series of experiments can we establish diagnostic standards and criteria for such things as dredged materials. Increased emphasis should be directed at studies to determine the chronic effects of exposure to moderate excess concentrations of a variety of contaminants.

The new Dredged Materials Research Program (DMRP) of the U.S. Army Corps of Engineers is an important step in the right direction. The DMRP should provide a great deal of valuable information for the more effective mangement of estuarine dredging and spoil disposal.

Alternatives to Present Practices

Even if we succeed in reducing sediment inputs to estuaries through enforcement of strict soil conservation measures, dredging will continue to be a persistent estuarine activity. Not only are estuaries naturally areas of relatively rapid sedimentation, but much of the material dredged from navigation channels is material previously introduced, and redistributed by prevailing estuarine circulation processes. Further, the increasing use of deeper draft vessels, and the increasing demand for pleasure boat marinas and facilities will require additional dredging.

Estuary-wide dredging and spoil disposal plans should be developed to ensure that maintenance channel dredging can be carried out without undue delays. Such plans should include the designation of a variety of types of sites (overboard, diked, et cetera) for disposal of different types of spoil. Certain kinds of spoil may have a greater environmental impact if disposed of in aerobic (oxygenated) diked areas, than if disposed of by conventional overboard methods within oxygen-deficient areas of an estuary. If regional plans are not developed promptly, the activities of a number of major ports will be seriously affected and will result in serious economic perturbations. These dredging and spoil disposal plans should be significantly flexible to provide a mechanism for decision making on requests for other types of dredging permits. The suggestion that a number of our major ports are "poorly located" is to some extent correct, but the suggestion that they should be moved is naive at best. Major ports could not be moved without serious economic upheaval, and the lead time to implement any such proposals would have to be decades. The growth of some ports located near the heads of estuaries should perhaps be controlled.

We should also direct more attention to more productive means of disposing of spoil. An example is the process developed by Professor Donald Rhoads of Yale University to make construction bricks from estuarine mud. Or we might consider taking railroad cars that haul coal to seaports and filling them on the return trip with dredge spoil that can be used to fill or reclaim lands that have been strip mined. Formation or nourishment of islands for recreational use is another possibility. Surely there must be other more ingenious ways of disposing of dredged material than dumping in estuaries or transporting it out to sea.

SOME CLOSING OBSERVATIONS

The great value of the estuarine zone is in the multiplicity of uses it serves, but herein also lies its vulnerability. Estuaries can support certain levels of shipping and transportation without a loss of commercial and recreational fish landings. Estuaries can tolerate some dredging and disposal activities without persistent damage to the biota or aesthetic

degradation. Estuaries also have a capacity to tolerate some human, industrial, and municipal wastes; and to assimilate some waste heat without suffering persistent and significant ecological damage. And, the biological resources of estuaries can be harvested at certain levels without seriously affecting future yields. Estuaries can serve all of these uses and still remain aesthetically pleasing environments for man's recreation—for his recreation. But an estuary's capacities to support these varied activities are finite. The ability of an estuary to tolerate each "environmental insult" before suffering significant ecological or aesthetic damage not only varies from estuary to estuary but varies in different parts of a given estuary as well. And, within any segment of an estuary it varies temporally. Uniform, invariant regulations and standards for the disposal of wastes, whether they are heat, nutrients, or dredged spoil, are environmentally naive. The only justification for their enactment is that it simplifies enforcement. A uniform speed limit of 25 mph is as irrational as one of 100 mph is irresponsible. Uniform estuarine regulations are wasteful of valuable natural resources—resources that should be used, and used responsibly. The philosophy of those crusaders who espouse cessation as the solution to all environmental problems is not viable. People live. They eat, they defecate, they procreate, and yes, they also need to recreate. This is not to imply that we should not insist on good waste treatment, on carefully supervised methods of dredging and spoil disposal, and on controlled mining of bottom and subbottom mineral resources. We should. We should insist on more.

Estuaries should be zoned. To date, formal zonation of the estuarine environment has been restricted primarily to that associated with military activities. Man zones his terrestrial environment into residential and industrial areas, and he sets aside portions of it for parks and forests for recreation. He identifies other segments of it for the disposal of his waste products. He does not make it an official policy to spread his garbage and trash uniformly over the landscape. He neither demands nor expects all parts of his terrestrial environment to be of equal quality.

Should he expect to be able to swim and harvest seafood in every part of every estuary? Segments of some estuaries should be identified as spoil disposal areas, other segments as the receiving waters for municipal and industrial wastes, others as sinks for the heated effluents from power plants, others as spawning and nursery areas, others for military activities, and others as fishing and recreational areas; still others should be preserved, or at least conserved in a wild state. These segments are not all mutually exclusive; there would be considerable overlap. And the spatial boundaries of the various zones should be defined as a function of time.

Because the primary reasons for the management of estuaries are to protect their biological resources and to conserve their aesthetic and recreational values, certain activities should be restricted more severely in some areas than in others and also during those periods when organisms are most vulnerable. During these vulnerable periods—generally the egg and larval stages—temperature standards should perhaps be more stringent, and dredging and spoil disposals should perhaps be restricted or prohibited in the important spawning and nursery zones. The zonation of estuaries would be much more difficult than zoning man's terrestrial environment, and some of these suggestions may not be applicable to small estuaries. The establishment and enforcement of an estuarine zoning system would require more than simple policing. It would require careful and intelligent planning and management. But planning and management by whom?

The establishment of a zoning system is contingent upon the assignment of priorities to the various uses. These decisions require not only scientific inputs but social and economic inputs as well. Decisions as to which activities are "most important" and what water quality standards are "good" or "acceptable" are largely value judgments—important to whom? . . . good or acceptable for what purpose? Natural scientists have no peculiar talents for making value judgments. Scientists can incontestably determine neither what uses of an estuary are most important nor even which are most desirable. In terms of gross monetary return, the most important uses of the estuarine zone are, according to the "National Estuarine Pollution Study," for military activities, for shipping, and for industry. But the monetary values of commercial and recreational fisheries are also very high although they are more difficult to estimate. And, if indeed, communication with nature is one of man's ultimate sources of happiness as Dubos and others have suggested, then the true worth of the recreational value of estuaries cannot be measured in dollars and cents.

Through science, we can learn to understand estuaries and even to control them in part, but scientists cannot unequivocally and decisively determine the ways in which we should control them. These decisions should be made by the citizens who are affected—by all of them.

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ACKNOWLEDGEMENTS

We thank M. Nichols, D. Hubbell, J. Conomos, and C. Zabawa for their suggestions. Contribution 116 of the Marine Science Research Center of the State University of New York.

SIGNIFICANCE OF CHEMICAL CONTAMINANTS IN DREDGED SEDIMENT ON ESTUARINE WATER QUALITY

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ABSTRACT

During the past several years, there has been a major change in dredged material disposal in some estuarine waters in the U.S. This change is largely the result of finding that many of the sediments of rivers and harbors contain potentially significant concentrations of chemical contaminants. Some water pollution control regulatory agencies have adopted dredged material disposal criteria which have caused more expensive methods of disposal.

A review of the information available today on the relationship between the presence of chemical contaminants in dredged sediments and water quality shows no technical justification for the general adoption of alternate methods of disposal at this time. Further, it is shown that some of the alternate methods of disposal may be more ecologically damaging than those previously used.

The U.S. Army Corps of Engineers initiated in 1973 the 5-year, $30 million Dredged Material Research Program, designed to provide a technical base of information for the determination of the most ecologically sound, technically, and economically feasible methods of disposal. This program shows great promise in providing needed information.

It is recommended that the overly restrictive dredged material disposal criteria advocated by some environmental activist groups not be adopted. The results of the Army Corps of Engineers Dredged Material Research Program and other studies should be used for establishing criteria.

INTRODUCTION

Many American waterways have a significantly recurring problem of accumulating sediments which eventually interfere with navigation. It is of economic and social interest to Americans to maintain the navigable waterways at a depth sufficient to allow the water transport of goods. Generally, the question is not one of whether or not the U.S. waterways should be dredged but is one of what method of dredging and dredged material disposal is in the best overall interest of society.

The process of removing settled solids from one location and depositing them in another has an environmental impact on both locations. The potential impact includes turbidity (cloudy water) stirred up at the dredging and dredged material disposal sites, mechanical damage to the aquatic organisms due to pumping for hydraulic dredging operations, burial of organisms at disposal sites, as well as toxicity to organisms arising from chemical contaminants in the sediments. It is the latter that causes sediments to be classified as polluted.

In the mid to late 1960's, increasing amounts of information were gathered which showed that the sediments in many estuarine environments contained amounts of chemical contaminants which could potentially lower water quality. By the early seventies, many Americans were caught up in the environmental quality movement. During this period, at the mere discovery of a chemical contaminant in the environment, activists would advocate large expenditures of funds for corrective action. In that spirit, the Federal water pollution regulatory agencies developed criteria which changed the method of disposal of dredged sediments for some areas of the country.

The new methods of disposal were predicated on the fact that the sediments contained amounts of chemical contaminants, which caused them to be classified as polluted. The alternate methods of disposal generally required a much greater expenditure of funds for the dredging operation. In some areas, the lack of a suitable alternate method of disposal has caused the dredging of the waterway to be stopped or greatly curtailed. As a result, the cargo vessels using the waterway had to either lighten their loads or seek an alternate port.

The situation that exists today in San Francisco Bay is a good example of this problem. The cost of

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dredging and dredged material disposal in the bay region has doubled during the past several years, largely as a result of environmental considerations. One would expect some problems associated with the presence of chemical contaminants in the sediments of the bay which, when dredged and disposed of in bay waters, have a significantly adverse effect on water quality. However, upon examination of the situation in the bay region, one finds that no one, including the water pollution control regulatory agencies and the environmental activist groups, has yet attributed any problems to the presence of chemical contaminants in sediments, which have a deleterious effect on water quality as a result of dredging and dredged material disposal activities.

Individuals knowledgeable in the behavior of chemical pollutants in natural waters examined the federal criteria which forced alternate methods of disposal; they raised serious questions about the validity of these criteria. As a result, the U.S. Army Corps of Engineers, which is one of the major dredgers of waterways in the U.S., initiated a program to determine which methods of dredging and dredged material disposal are in the nation's best interests. Their headquarters for this project is at the Waterways Experiment Station (WES) in Vicksburg, Miss. In addition, a number of Corps of Engineers districts have initiated regional research programs designed to evaluate the potential problems of dredging and dredged material disposal. This report discusses the progress that has been made in the control of chemical pollutants in waterways to be dredged.

This report is not intended to be a discussion of all of the various problems associated with dredging and dredged material disposal. It instead focuses exclusively on one of the most significant problems of the past few years in the area of estuarine water quality. This problem requires congressional attention in order to develop a more meaningful approach to the protection of water quality in U.S. estuaries with dredging and dredged material disposal activities. It should be emphasized that other aspects of dredging and dredged material disposal should also receive congressional attention. These problems include the development of a more effective land erosion control program to reduce the need for dredging, the selection of a few harbors and waterways as principal ports for deep draft vessels, the more effective control of chemical and biological contaminants arising from domestic, industrial, and agricultural activities, and the development of more effective means for allocation of the nation's estuarine and marine resources. Many of these topics are covered in other authors' contributions to the U.S. EPA overall report to Congress on estuarine water quality. They are beyond the scope of this paper.

This report does not attempt to provide detailed documentation of each point raised. Instead, it consists of a synthesis of the author's views, which are based on his having been actively involved as a teacher, researcher and advisor to governmental agencies and industry on the environmental impact of dredging and dredged material disposal. The U.S. Army Corps of Engineers Dredged Material Research Program (DMRP) includes comprehensive literature reviews prepared by various contractors, which provide documentation of the various points covered in this report. Anyone interested in additional discussion and documentation should contact the author and/or the Corps of Engineers Dredged Material Research Program at the Waterways Experiment Station, Vicksburg, Miss.

Two Corps reports are especially pertinent as backup information to the discussion presented in this report. The first is by Boyd et al. (1972), and presents a review of the overall problems associated with dredging and dredged material disposal. The second report, by Lee and Plumb (1974), presents a detailed review of the literature on the potential significance of chemical contaminants in sediments as influenced by dredging and disposal activities.

HISTORY OF THE PROBLEM

Prior to the environmental movement, dredged material was generally disposed of in the most economic manner possible, usually transportation to and disposal in deeper waters. By the late 1960's, and early 1970's, environmental activist groups and some federal and state pollution control agencies were advocating on-land disposal. Large amounts of funds have been expended for land disposal areas.

During the past three years, there have been several attempts on the part of federal and state water pollution control regulatory agencies to develop dredged material disposal criteria. These criteria were based on a limited scope study conducted in the Great Lakes, and were unfortunately made applicable to estuarine and marine systems as well. In retrospect, it appears that such criteria were not suitable for the Great Lakes, much less other waters throughout the country. As a result of the use of these criteria, sediments in many parts of the country were classified as polluted when significant doubt exists as to whether this was the case.

NATURE OF THE PROBLEM

The rapid changes in dredging and dredging material disposal methods during the past few years have

probably created as many problems as solutions. In some areas, dredging has stopped. In other areas, escalating costs are forcing private dredgers out of business. Those who continue operating must absorb the increased costs. Yet, some of the more expensive alternate methods of disposal are probably more ecologically harmful than the previous methods.

It is difficult to estimate at this time the total magnitude of the additional cost of alternate methods. However, in a survey of the various Corps of Engineers districts, it was found that environmental quality factors raised the cost of dredging by 10 to 20 percent. For some Corps of Engineers districts, the increase represented 50 to 60 percent additional cost.

It is impossible to estimate the total cost for alternate methods of dredged material disposal in estuarine waters. However, it is reasonable to expect that several tens of millions of dollars are being spent each year for alternate methods of disposal because of arbitrarily adopted criteria which cause dredged sediments to be classified as polluted. Yet, there is no evidence that the relatively economical sediment disposal methods used in the past had significant adverse effect on water quality.

Many areas are not finding the alternate methods of disposal, such as on-land disposal, feasible, and as a result must barge the dredged material further out into the open ocean. For example, the New York District of the Corps of Engineers estimates that they are spending about 1.2 million dollars per year out of a total dredging cost of 5 million dollars for additional transport of dredged material to open water. The New York District Corps of Engineers points out that these figures do not include the increased cost of goods such as oil, because partly loaded or shallow draft vessels must be used.

The New York District also reports that several marinas and small volume dredging companies have had to go out of business because they cannot afford the increased costs of transporting the material to the open ocean. Also, because of environmental concerns, dredging has ceased in some east coast harbors, such as Baltimore. Although the total increase in cost is unknown, alternate disposal methods place a substantial burden on the public without any apparent benefit in terms of improved environmental quality.

PROBLEMS WITH ON-LAND DISPOSAL

In many areas, on-land disposal with complete containment of the water associated with the sediments is not possible; so near shore diked area disposal was adopted. Generally, on-land and in-water diked disposal areas have overflows that enter nearby watercourses. Thus, this disposal approach may be more harmful to aquatic ecosystems than the disposal of dredged sediments in deeper waters.

Those knowledgeable about the behavior of pollutants in natural waters have known for some time that the primary area of concern for chemical contaminants in natural water systems is fine particles. Coarse particles readily settle to the bottom. The fine particles often contain the greatest concentration of chemical contaminants and, because of their slower settling rates, have greater opportunity for interactions with aquatic organisms.

Some of the on-land or dike disposal areas nearshore have been operated in such a way as to allow only a relatively short period of time for the settling of finer particles before returning the excess water to the nearby watercourse. This means that if there is any adverse effect from dredged material, it would occur to the maximum possible extent with on-land or contained disposal. By contrast, any adverse effects of chemical contaminants associated with dredged sediments would generally be expected to be minimized in open water disposal because, in general, open waters allow much greater mixing of the contaminants with the surrounding waters. This mixing would tend to rapidly dilute the chemical contaminants below critical threshold concentrations for the organisms present in the water column. Moreover, on-land disposal would bring contaminant concentrations into contact with the most sensitive forms of aquatic organisms, since nearshore waters serve as the nursery grounds for the juvenile forms of many aquatic species. Thus, it is possible that in some areas the more expensive on-land disposal methods in use during the early 1970's, have done more ecological damage to the water bodies than have the traditional deep water disposal methods. In addition, on-land disposal may also lead to contamination of terrestrial ecosystems as well as nearby watercourses. However, at this time, little is known about the uptake of chemical contaminants by terrestrial plants grown on polluted dredged sediments.

It is clear that, as normally practiced today, many of the alternate, more expensive ways of dredged material disposal may not be less ecologically damaging. Frequently, those who advocate alternate methods based on the presence of chemical contaminants, justify the increased expenditure by citing the lack of knowledge of the environmental impact of aquatic disposal. They assert that the conservative approach should be used in those situations where there are questions about the impact on aquatic ecosystems. This argument has some validity where the concern is over the introduction of a chemical contaminant

into the environment. It is not technically valid, however, for dredging and dredged material disposal since the contaminants are already present in the environment and most importantly, since the alternate methods of dredged material disposal could produce significant environmental quality problems.

DREDGED MATERIAL DISPOSAL CRITERIA

In 1972, two developments of major potential significance to the disposal of dredged materials occurred. The first was the passage of the 1972 Amendments to the Federal Water Pollution Control Act. This act required the U.S. Environmental Protection Agency (EPA) to propose water quality criteria by October 1973. The other important event was the 1972 release of the National Academies of Science and Engineering (NAS-NAE) Water Quality Criteria (NAS-NAE, 1972). These criteria represent several years of work on the part of scientists and engineers throughout the U.S. in assessing the significance of various physical, chemical, and biological contaminants to potential uses of fresh and marine waters. The two events are closely related in that the criteria proposed by EPA in October 1973, were essentially based on the July 1972 NAS-NAE water quality criteria. Both documents are potentially crucial to dredging because they suggest that agencies which regulate water quality standards significantly reduce the permissible concentrations of chemical contaminants.

The most crucial change stemmed from the discovery that pollutants could be chronically toxic. Previous water quality standards throughout America had been based on acute lethal toxicity (i.e., the relatively high levels of chemicals that cause the death of organisms within a few days of continuous exposure). However, researchers found that continuous lifelong exposure of aquatic organisms to relatively low levels of chemical contaminants would result in impaired growth and/or reproduction. The NAS-NAE concluded that, in order to provide the ultimate protection to aquatic life, water quality criteria must also be based on chronic toxicity levels.

The full impact of the NAS-NAE water quality criteria is yet to be manifested. The main problem is that although the National Academies released the criteria in 1972, it took two and one half years for EPA and the Government Printing Office to print them.

The importance of the new NAS-NAE criteria is that they will eventually become water pollution control standards because they are essentially being adopted by EPA as a basis for their October, 1973 Proposed Water Quality Criteria. It is likely that attempts will be made to use these standards to govern dredging and dredged material disposal. For example, EPA Region IX has recently proposed revised dredged material disposal criteria for which they use as a justification the EPA October 1973 Proposed Water Quality Criteria. However, this presents a problem in that the criteria developed by the NAS-NAE and promulgated by EPA are applicable to forms of chemicals in a relatively simple chemical state. In natural waters, chemical contaminants exist in a wide variety of forms, many of which are much less toxic than those simpler forms frequently used to test aquatic toxicity. For instance, the chemicals associated with the solids in sediments being dredged would generally be in the least toxic form. Therefore, any attempts to apply the EPA proposed criteria to dredging would likely be highly over-restrictive in assessing the potential toxicity of chemical contaminants associated with sediments.

In developing dredged material disposal criteria, emphasis must be given to the role that dredging and dredged material disposal plays in affecting the significance of chemical contaminants on water quality in a particular region. The problem is not one of determining whether or not the sediments are contaminated. The sediments of the majority of the U.S. harbors and waterways are contaminated by chemicals of municipal, industrial, and agricultural origin. These contaminants do have an adverse effect on water quality in many U.S. estuaries. The basic question, however, is what is the impact of dredging and dredged material disposal in altering the significant adverse effects of these chemical contaminants on water quality in the region.

CURRENT RESEARCH

By the early 1970's, the funds supporting research in the development of water quality criteria had been greatly curtailed in an attempt to cut back on federal spending. Currently, little work is being conducted on the development of new criteria for the hundreds of new compounds that are being produced each year, much less the thousands of compounds that have been produced and are being introduced into the environment today. It appears that, unless a major change takes place in the approach to funding in the water quality criteria development area, it will be difficult to develop meaningful criteria which can be used to properly evaluate the full significance of chemical contaminants associated with sediments in rivers and harbors.

With respect to dredged material disposal problems as they affect estuarine pollution, perhaps the most significant event of the past three years was the funding of the $30 million, 5-year research program being conducted by the U.S. Army Corps of Engineers, Vicksburg Waterways Experiment Station. In many parts of the country, typical costs of dredging have increased from 30 to 40 cents per cubic yard to 50-60 cents per cubic yard. In some cases, because of environmental considerations, the costs of dredging and dredged material disposal approach $10 per cubic yard. The U.S. Army Corps of Engineers' current annual budget for dredging and dredged material disposal is approximately $200,000,000 a year. While the dollar magnitude of the 5-year research program is substantial, it should be noted that if this program results in savings of one to two cents per cubic yard, it will pay for itself during its lifetime.

The Corps of Engineers Dredged Material Research Program (DMRP), while originally motivated primarily by a lack of knowledge on environmental impact of dredging and dredged material disposal, is providing information on constructive use of dredged materials, such as in the development of wildlife habitat. Most importantly, from the point of view of this discussion, this research project will provide valuable information that can be used to develop meaningful dredging and dredged material disposal criteria. These will enable those responsible for environmental resource management to evaluate the potential environmental impact of chemical contaminants in sediments which are scheduled to be dredged. From these studies, criteria will be developed which will be transformed into standards for dredging and dredged material disposal.

CURRENT SITUATION

At present, although dredged material disposal criteria are supposed to be uniform across the U.S., there is considerable confusion in the estuarine dredging field concerning the criteria which determine whether a given sediment contains sufficient concentrations of chemical contaminants to warrant alternate methods of disposal. A situation exists whereby each EPA region is able to promulgate its own criteria irrespective of EPA's efforts to establish uniform criteria. To develop their criteria, the regional EPA districts often resort to the bulk analysis approach rather than attempt to assess what part of the chemical contaminants may adversely affect water quality or aquatic life as a result of being made available by dredging or dredged material disposal.

It is apparent that one of two things must take place in order to eliminate the dredged material disposal criteria chaos that exists today. Either the EPA regions must utilize the criteria established by EPA national headquarters, or Congress must appropriate sufficient funds to strengthen the technical competence of the regional staffs so that these staffs could develop meaningful criteria for their particular regions. Frequently, the individuals responsible for making decisions of this type have limited knowledge of the environmental chemical behavior of pollutants in natural water systems. These individuals usually play it safe by taking the conservative approach and assuming that everything is polluted. Thus, they cause the public to spend large amounts of money for alternate methods of disposal. Since dredging is largely funded by tax dollars, such an approach leads to increased government spending and accelerated inflation. In the opinion of many, the adoption of arbitrary bulk chemical criteria which have no relationship to potential effects on water quality may do much greater harm to the financial and ecological resources of a particular area than the utilization of the available information to determine whether a particular chemical contaminant present in sediments is likely to have an adverse effect on water quality.

Another significant problem with water pollution control agencies adopting arbitrary dredged material disposal criteria is that this will eventually further erode the public's confidence in the ability of the agency to act on its behalf. Many individuals already question whether the approaches being used by water pollution regulatory agencies are in the overall best interest of the public. There is an urgent need for these agencies to gain credibility in the environmental quality control area.

The first attempt to establish criteria relative to the pollutional tendencies of a given concentration of chemical contaminants in sediments utilized what is termed "bulk criteria." Bulk criteria are based on an examination of the total content of the sediments for a particular element or compound. Use of these criteria generally assumes that all the forms of that element are equally toxic. Those familiar with aquatic toxicity know that this is certainly not the case. There is no relationship between the bulk composition of sediments and the water pollution tendencies of the chemical contaminants present in the sediments.

In an effort to eliminate the problems associated with bulk criteria, EPA and the Corps of Engineers

developed the elutriate test. This test exposes the sediment sample to a known volume of water and then allows the chemical contaminants to be leached from the sediments. The elutriate test is primarily designed to examine potential problems due to the release of chemical contaminants from sediments during the dredging and dredged material disposal process. The primary problem with the elutriate test is that it has not yet been properly evaluated for the wide variety of sediments that occur in various estuaries and waters throughout the country. This leads to confusion over the interpretation of the test results. The Corps of Engineers DMRP is devoting considerable effort to finding a remedy for this situation. It is likely that within a year or so the elutriate test will become a standard tool to evaluate the potential deleterious effects of chemical contaminants such as copper, DDT, et cetera, on the water near dredging and dredged material disposal sites.

In addition to developing the elutriate test, the Corps of Engineers DMRP is funding studies which are designed to evaluate the potential deleterious effect that will occur on benthic organisms at the dredged material disposal site. It is likely that a standardized bioassay procedure will be developed as part of this research program. Within a few years, water pollution control regulatory agencies will likely have the tools necessary to evaluate, prior to dredging, whether the chemical contaminants present in the sediments will have an adverse effect on water quality at the dredging and dredged material disposal sites.

It is in the best interests of the public, overall, to adopt interim dredged material disposal criteria which prevent the deposition of dredged materials in ecologically sensitive areas, such as significant fish spawning areas and shellfish beds. The interim criteria should be based on all available information on the significance of chemical contaminants present in dredged sediments to aquatic ecosystems. If alternate methods of dredged material disposal are advocated because of these criteria, a careful review should be conducted to ensure that the alternate methods do, in fact, minimize environmental impact of the chemical contaminants in sediments in both terrestrial and aquatic ecosystems. These interim criteria should be modified according to information developed as a result of the Corps of Engineers Dredged Material Research Program and other studies.

RECOMMENDATIONS

The following recommendations are proposed to serve as the basis for developing the technical information needed to evaluate the environmental impact of dredging and dredged material disposal in estuarine waters of the U.S.

1. The U.S. Army Corps of Engineers Dredged Material Research Program, devoted to evaluating the environmental impact of dredging and dredged material disposal (including the evaluation of various beneficial uses of dredged material) should be continued, at least at the currently programmed funding level, for the duration of the program.

2. The overly restrictive position based on bulk chemical criteria advocated by some environmental activist groups and water pollution control regulatory agencies at the local, state, and federal level, should not be adopted.

3. The current fragmented approach toward establishing dredged material disposal criteria and standards at the various regions of the EPA should be eliminated and national criteria should be adopted. The national criteria should provide a basis for evaluating the potential significance of chemical contaminants present in dredged sediments. In applying these criteria, consideration should be given to local factors which would influence the significance of chemical contaminants at a particular dredging and/ or dredged material disposal site. These criteria should be developed jointly by individuals representing the EPA, Army Corps of Engineers, and others knowledgeable about the environmental impact of dredging and dredged material disposal.

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LIMITING FACTORS THAT CONTROL DREDGING ACTIVITIES IN THE ESTUARINE ZONE

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ABSTRACT

The current level of dredging activity for navigation channels (250,000,000 cubic yards annually) is producing substantial effects in the United States estuaries. These effects derive from 1) physical changes at the dredge site and release of substances from the sediment during the dredging; and 2) physical changes at the disposal area—filling of deeper areas and smothering of bottom dwelling organisms—and release of substances to the waters of the disposal area. The recent increased use of diked disposal areas, along the shorelines at increased costs, does not eliminate all of the environmental effects. Since soil erosion throughout the watershed is the primary source of the sediments, the obvious management strategy is control at the source. In addition to the recognized desirability of soil conservation, erosion control should be identified as essential to prevent continuing damages to estuaries.

INTRODUCTION

Navigation and cargo transport are valuable uses of estuaries that must be considered in formulating strategies and policies for management of U.S. estuaries. The optimization of policies to meet multiple-use objectives for estuaries presents intriguing and perplexing challenges with unavoidable intertwining of scientific and political considerations. Policy development that does not adequately consider both kinds of considerations may lead to the extremes of thoughtless waste of natural resources or to excessive preservation. Examples of both extremes can be found in the United States today.

Creation and maintenance of navigation channels in the United States is a substantial activity of the Federal government through projects carried out by the U.S. Army Corps of Engineers. The scope of recent activities and associated partially understood environmental effects have been reviewed by the Army Corps of Engineers[1]. The level of dredging activity has been approximately 250,000,000 cubic yards annually in recent years for just maintenance, and the magnitude has led to questioning of the acceptability of the various environmental effects. The rather high level of activity has developed as the result of two different processes. Increased land utilization for agricultural, industrial, and domestic purposes in the watersheds that feed the estuaries has led to increasing amounts of soil introduction. Concurrently, new and expanded ports have been developed, along with increasing use of deeper draft cargo vessels. In some cases the construction of dams to produce reservoirs has reduced the flow of soil to the estuaries but the reservoirs are rapidly accumulating sediment. Past and present failure to control erosion has led to a continued filling of the estuaries. In many cases, fine-grained sediment has been introduced to the point where resuspension by wind, waves and tidal currents leads to rapid transfer into the quieter waters of deep channels and rapid filling of navigation works.

Failure to develop effective policies will impact the economics and natural resources of many coastal states. As shown in Table 1, nearly every coastal state had maintenance and new projects proposed for FY 72. Many of the proposed work programs were not carried out, either for a lack of funding priority or because of questions concerning environmental effects and whether or not the optimal approach had been proposed. The economic consequences of the projects are not related to proposed yardage of dredging by a constant proportionality. For example, Maryland's project of 0.4 million cu yd, (a small part of the national program), was not carried out in FY 72 and the Baltimore Evening Sun recently headlined, "Port Dredging Delay Costs City $30 Million."[2] This article describes the economic impacts of the continued delay in maintenance dredging with 42-foot authorized channels having shoaled to 36 feet and at some points to 27 feet. Similar substantial economic impacts are occurring in other regions, notably San Francisco, Mobile, Galveston and the Great Lakes. Continued stalemates will have increasing impacts on the citizens affected and the adversary postures of national and

Table 1.—Dredging proposed for Fiscal Year 1972

State	Maintenance	New Projects
New Hampshire	1.7 million cu yd	4 million cu yd
New York	2.4	5.4
Pennsylvania, Delaware, New Jersey	1.8	8.6
Maryland	0.4	—
Virginia	2.0	0.1
North Carolina	6.0	0.1
South Carolina	6.9	—
Georgia	1.7	—
Florida	2.8	—
Alabama	16.5	3.2
Mississippi, Louisiana	74.4	21
Texas	28.7	17.6
California	4.9	2.9
Oregon	0.4	4.2
Washington	0.1	1.1

Data source: reference 1.

state agencies will have to be modified toward collaboration to develop multiobjective policies that balance economic and conservation considerations.

The national dredging effort during the past decade is shown in Figure 1 in terms of yardage and dollars. The decrease following FY 66 was the result of a twofold decrease in new projects and the increases since FY 69 are primarily associated with maintenance dredging. The rapid rise in costs since FY 72 appears to be due to changes in disposal practices to meet presumed environmental requirements. It should be noted that in some localities increased costs have been much greater than average increases shown in Figure 1 and the national effort cost statistics are ballasted by the high volume-low cost operations in Mississippi. Local project costs have gone as high as 10 times the national average or up to $5 per cu yd. In some cases where costs have increased drastically, the projects cannot be justified on the basis of a cost-benefit analysis and the projects have not been undertaken. The national trend, shown in Figure 1, appears to be substantial and the following discussion attempts to outline the considerations that are leading to the increasing costs and delays.

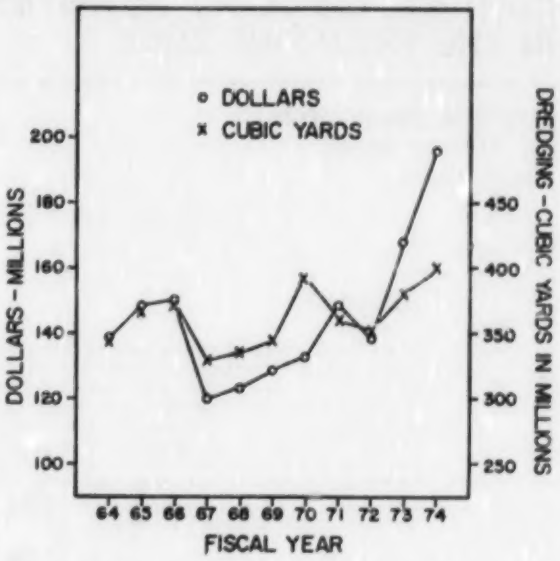

FIGURE 1.—Recent federal dredging activities in volume and costs. Data supplied by U.S. Army Engineer Waterways Experiment Station.

OBSERVED AND POTENTIAL EFFECTS OF DREDGING AND DISPOSAL

The effects of channel construction and maintenance occur at the construction location and at the disposal location. Considering first the construction activities, the effects may be categorized as follows.

Direct Effects of Dredging

The excavation of channel includes the removal of the living organisms and the loss of a fraction of the total local population of benthic (bottom-dwelling) organisms. Harvestable species, such as oysters, clams, shrimps, and so forth, may be involved as well as species that are eaten by bottom grazing fishes. The presence of a particular species is strongly related to the physical character of the bottom, particularly with respect to grain size, degree of compaction, or firmness and organic content. When a channel is cut, the newly exposed material is usually firmer than the previous surface and repopulation is limited to those species that find the new conditions amenable. While channel construction reduces the area available to some species, channels in the nation's estuaries occupy only a small fraction of the total area. The effects on the local populations are of questionable quantitative significance and the losses appear to be outweighed by the usefulness of the channels.

Indirect Effects of Dredging

The bottom materials of estuaries are composed primarily of quartz (sands), aluminosilicates (clay) and calcium carbonate (skeletal fragments). These materials are predominantly inert. However, organic materials are also present and many elements (including transition or heavy metals) are present in lesser abundance in association with the surfaces of the bulk material and the organics. The organic materials may come from plant and animal life on the watershed, plant and animal life in the estuary, and discharges from domestic and industrial activities. As the estuarine sediments are being deposited, much of the organic material is metabolized by microorganisms that flourish at the sediment surface. However, not all of the organic material is metabolized and some becomes buried as additional materials accumulate at the sediment surface. Metabolism occurs within the sediment and, at some variable depth below the sediment surface, the supply of oxygen is inadequate to support the metabolic rate and the metabolism is dominated by anaerobic or oxygen-free processes. The predominant anaerobic process is the use of sulfate ions to support the oxidation of organic materials with the result that hydrogen sulfide is produced and mineral sulfides may be formed in the sediments, and hydrogen sulfide (rotten egg or swamp gas) accumulates in the waters within the sediment.

As the metabolism proceeds, nitrogen and phosphorus compounds (plant nutrients) are released to the waters within the sediment. Some metals, particularly manganese and iron, are solubilized from the minerals and appear in sediment waters in concentrations greater than that of the overlying waters. The net result of these processes is that many sediments that are considered for dredging have relatively high concentrations of biologically and chemically active substances. For example, hydrogen sulfide reacts rapidly with dissolved oxygen and contributes substantially to the so-called chemical oxygen demand of the sediments as well as acting as a direct toxicant.

The presence of growth promoting (nutrients) and growth inhibiting compounds (toxicants) leads to questions concerning the effects of release of these substances during the disturbances associated with dredging. It is pertinent to note that molecular diffusion naturally transports these substances to the overlying water and the dredging disturbance is primarily a local, intense acceleration of the transport process. Most of the dredged material is transported to the disposal site and effects of nutrients and toxicants are usually more important at the disposal site.

While it should be trivially obvious that environmental effects are quantitative in character, for example, the release of one pound of an active substance per day may have discernible effects in a particular estuarine location and almost imperceptible effects in another estuarine location, efforts continue to classify sediments and dredging activities on the basis of the composition of the materials involved. Inspection shows that a guideline or standard that would protect all estuarine locations from environmental effects would be unnecessarily restrictive and lead to a waste of public monies.

The point to be made is that release of active chemical compounds is a potential limiting factor on the acceptability of any particular dredging operation, but the substantialness of the limitation can only be determined for each particular location and specific activity.

A second kind of indirect effect that persists after the channel construction has been completed derives from changes in the currents and circulation caused by the presence of the channel. The intrusion of seawater into an estuary depends on the freshwater flow rates, the strength of tidal mixing and the depth of the estuary. A new channel has the potential for increasing the intrusion and therefore the saltiness along the length of the estuary. Many activities and requirements of estuarine organisms are related to the salinity of their environment. Some fishes spawn in fresh water and others spawn in salt water but require brackish or low-salinity waters during their maturation into adults. Increases in salinity have the potential for reducing the amount of habitat available to these species. Success of some estuarine organisms, notably the oyster, reflects the intolerance of some predators, the oyster drill, to low salinities and increasing salinities potentially extend the range of the predators into the estuary. Once again, the potential of these effects can be recognized but only evaluated in the context of a specific location with its particular biota and physical characteristics.

Turning next to the effects of open water disposal, they may be categorized as follows.

Filling of Deeper Areas—Open Water Disposal

The deep regions of estuaries may play a unique role in supporting fish by providing havens during the winter cold season, as has been observed for striped bass and croakers in northern Cheasapeake Bay. The deeper water is saltier but warmer than

the surface waters in the winter and the existence of the deep water refuges may be critical in avoiding "cold kill" of these fishes or migration of the fishes to the ocean. The significance of this consideration varies from estuary to estuary and no generalizations are possible. While the values of naturally occurring deep regions have been identified, there does not seem to have been justification for deliberately over-deepening stretches of navigation channels but this approach might be considered to mitigate the loss of the natural areas, if the water quality in the navigation channels is suitable.

Smothering of Bottom-Dwelling Organisms and Repopulation

Open water disposal of dredged material may result in covering rather large areas with the spoil. Discharged materials have been observed as deposits in areas manyfold larger than the nominal disposal site.[3,4] The potential for this effect is substantial since the annual volume of dredging could cover 268 square miles to a depth of 1 foot. The degree of dispersal depends on the nature of the spoil, the strength of the currents at any particular disposal site, and on the kind of dredging operations since hopper dredging produces less opportunity for dispersal than hydraulic dredging.

If the dredged material is similar to the existing material at the disposal site, the effects of smothering may be transient and repopulation to replace the killed organisms could occur. This may be the case frequently for new work, but maintenance dredging commonly involves fine-grained material that accumulates preferentially in the dredged channels. Transfer of fine-grained materials to locations with existing firmer, coarse-grained sediments may be expected to produce long-term population changes as reported in reference 3, and, even though some species reappear in large numbers, the community structure will be changed. Such changes in the bottom of a habitat may be a major limitation on spoil disposal in estuaries.

Smothering may be a particularly severe limitation in areas of high water clarity, since benthic grasses may be an important part of the community and repopulation of denuded areas will be slow. Even in the warm waters of Florida, the return of seagrasses to damaged areas has been observed to require many years. Similarly, corals regenerate slowly and losses are not readily replaced.

Modification of Currents and Flushing Rates

At locations where the dredged material is not widely dispersed, filling to substantial depths will occur and such environments have obviously weak currents. The reduction in cross-sectional area through which the water can flow may reduce the total flow and, thus, the flushing or renewal of the waters in the estuary. Since the salinity distribution in an estuary depends on rates of river water input and the circulation, the reduction in depths may have an additional effect in terms of changes in the salinity distribution. The potential for these effects is rather easily identified, but there do not seem to be examples where it has been quantitatively significant.

Release of Sediment Constituents to the Water

As noted above, sediments contain biologically active substances, both nutrient and toxic materials. The possible release of these substances during open water disposal and following deposition of the discharged materials has led to questioning the acceptability of such operations and is a major source of current arguments.

The Environmental Protection Agency has put forth "criteria for determining acceptability of dredged spoil disposal to the Nation's waters" (reference 1, page 32). Criteria (h) reads, "...when concentrations, in sediments, of one or more of the following pollution parameters exceed the limits expressed below, the sediment will be considered polluted in all cases and, therefore, unacceptable for open water disposal."

SEDIMENTS IN FRESH AND MARINE WATERS

	Conc. % (Dry Wt.)
Volatile solids	6.0
Chemical oxygen demand	5.0
Total Kjeldahl nitrogen	0.10
Oil-grease	0.15
Mercury	0.001
Lead	0.005
Zinc	0.005

Some of the deficiencies associated with numerical concentration limits may be seen from consideration of the zinc "criterion." The average abundance of zinc in rocks and soils on the surface of the earth is 0.01 percent[5] and most naturally occurring materials would fail to meet the criterion but it is difficult to consider them polluted. The sediments being dis-

charged to the Chesapeake Bay in the Susquehanna River flow average 0.05 percent zinc[6] and nearly all of the sediment in Chesapeake Bay would not meet the criterion. However, there is no evidence that these concentrations impair the environment of the aquatic organisms in Chesapeake Bay.

There appear to be two major deficiencies in the concentration criteria. The first is that the quantity involved in any particular activity is not considered; i.e., disposal of 100 tons of sediment with 0.05 percent zinc could potentially result in the release of 0.05 tons or 100 pounds of zinc to an estuary and, similarly, with numerical criterion of 0.005 percent zinc, the release could be 10 pounds. Whether or not the resulting environmental perturbation in either case would be significant depends on the particular estuary and the rate of the release. Each particular operation should be considered in terms of the time and spatial intensity of the perturbation and whether or not appropriate water quality criteria will be exceeded in a sufficient area for a sufficient time to produce an unacceptable effect on the aquatic populations in the estuary.

For sediments, the gross or total composition does not seem to be the appropriate aspect for consideration and this is a serious deficiency in the existing criteria. Using zinc as an example, the pertinent information is the availability of the zinc to the biological systems, both during the disposal operations and after the dredged material has been deposited, i.e., both short and long-term release. Much of the sediment zinc may be immobile and, thus, innocuous. An approach to evaluating the short term release is the elutriate test described under the EPA Ocean Dumping Final Regulations and Criteria 227.61 (C)[7] in which the material proposed for disposal is shaken with water from the disposal site and the resulting solution is analyzed for released substances. At present, there is no accepted way of evaluating the potential long-term release or effects on bottom-dwelling organisms. A possible procedure would be the examination of the characteristics of the material at the proposed dredge site by analysis of the pore or interstitial waters of the sediment and the bottom-dwelling, deposit feeding organisms. If substances are being released to the overlying waters, the pore waters will be greatly enriched and an estimate of the rate of release can be found from the contrast between the concentrations in the pore waters and the overlying waters. If substances are entering the biological food chains through deposit feeding organisms, the significance of this process could be judged from the amounts appearing in such organisms.

The purpose of drawing attention to the inadequacy of numerical concentration limits for dredged materials (that are analogous to effluent standards) is that such an approach will frequently either not properly protect environmental values or unnecessarily restrict some useful activity. Just as a responsible physician will not make a diagnosis or prescribe treatment without studying the individual patient, limitations on estuarine dredging due to release of materials to the water can only be developed on the particulars of each individual proposed activity. Environmental requirements of estuarine organisms can be established in a straightforward way and be broadly applied as water quality criteria, but the meeting of those requirements cannot be mandated by adoption of arbitrary input concentration limits, despite administrative enthusiasm for simple, universal regulations.

Creation of Land Along Shorelines and Islands

In view of the above effects of open water disposal, confined or diked disposal areas have been increasingly used. Frequently, the shallow areas along the estuary shorelines have been used. Such use causes a permanent loss of valuable estuarine environment and, in some cases, has produced land that has only limited usefulness for long periods of time. Current research directed by the Army Corps of Engineers is aimed at developing techniques and engineering practices to improve the quality of the land in the diked disposal areas. However, in view of the limited area of estuaries in the United States, conversion of present estuarine water bodies to fast land is not an attractive long-term strategy.

One limitation on the use of shoreline diked disposal is the necessity of retaining sufficient width to permit the discharge of storm runoff without excessive upstream flooding. The Potomac estuary below Washington, D.C., is a good example in that past diking produced useful land for Washington National Airport, Blue Plains Treatment Plant, and so forth, but further diking would likely produce an unacceptable reduction in the capacity to discharge flood waters. Changes in the width of an estuary also will have effects on the circulation, flushing, and salinity distribution to change the character of the estuary.

In addition to the ready generalization that destruction of shallow water and marshland habitats on a large scale and continuous basis is a waste of our limited resources, few property owners view with favor the construction of a diked spoil disposal

facility adjacent to their lands and the states are reluctant to enter into condemnation proceedings. This is a practical limitation that is limiting dredging in estuaries and will also be a serious limitation to upland or dry land disposal.

The use of diked disposal areas has been proposed for materials that have been classified as polluted. As noted above, such classification may not be an accurate evaluation of the environmental hazards associated with the materials, but, in addition, it is not clear that diked disposal solves the problem. The process of dredging unavoidably involves the mixing of the sediment with large quantities of water. If biologically active materials are released to the water, the discharge of the water from the diked area into shallow waters with little dilution capacity would be expected to display greater environmental effects than would have occurred with open water disposal. Many estuaries have sediments with high concentrations of iron sulfides that are stable in the absence of oxygen. With diked disposal, the percolation of oxygenated waters through the material may produce the familiar acid mine drainage waters that result from the production of sulfuric acid upon oxidation of iron sulfides. Evaluation of the significance associated with these potential effects requires quantitative considerations; i.e., what fraction of the habitat is modified, for how long, to what degree from water quality criteria.

SHORT-TERM AND LONG-TERM POSSIBILITIES

The current research program directed by the Army Corps of Engineers should provide improved, factual information upon which assessment of new short-term options can be based. Where open water disposal is not suitable (habitat modification through physical effects may be expected to be a more severe restraint than pollutional effects), diked disposal with adequate engineering practices may be a viable option. Reduction in environmental damage due to runoff and leaching from the disposal sites may lead to increased costs and more complex disposal technology. The acceptability of such operations should be increased as techniques for making the disposal areas useful as land for human activities or wildlife habitat are developed. The optimal procedures will have to be developed for each estuary with due regard to its socio-economic setting.

However, these approaches to ameliorating damages to estuaries from dredging will be increasingly costly as the cheaper options are exhausted. This trend is clearly shown in the pattern illustrated by Figure 1. As appropriate open water estuarine sites and adjacent shoreline areas are fully utilized, upland and deep ocean disposal become the only alternatives and costs can be expected to increase by tenfold or more. As costs move to tens of dollars per cubic yard, the alternate of vigorous action to attack the root of the problem becomes more attractive. Failure to regulate human activity has led to well-documented increases in the rates of soil erosion[5]. Problems in the national dredging program are inversely related to successes in the national soil conservation program. It has long been the view of this writer that sedimentation at increased rates poses the most serious threat to the nation's estuaries and the dredging problems simply highlight the continuing damage being done through failure to control erosion.

Substantial progress has been made in the research, development, and application of procedures to reduce erosion. Many examples of successful use of such knowledge could be cited; however, more obvious are the failures to use such knowledge. Poor agricultural practices, slipshod road construction, and aggravated stream erosion due to storm water from paved areas are easily observed. The federal program of advice and information dissemination to the states, counties and individuals has been sound, but action is primarily at the county and individual level. At present there are only local incentives and the pollutional aspects of the soil erosion in one county harming the estuarine resources, including navigation, of an adjacent county have received little attention. With increasing costs and greater recognition of damages due to upstream negligent or improper practices, the need for action should be a matter for federal concern and activity by the appropriate agencies.

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ENVIRONMENTAL ASPECTS OF DREDGING IN THE GULF COAST ZONE WITH SOME ATTENTION PAID TO SHELL DREDGING

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ABSTRACT

The coastal zone is a rich national asset closely tied to our economy. Man's activity in the coastal zone has caused this rich national asset to be placed in jeopardy. "The National Estuarine Study" (1970) estimated that approximately 85 percent of the estuaries located on the gulf coast have been modified because of man's activities.

Shell dredging activities in the gulf coast region indicate a slight downward trend and are expected to decline as a whole in the future. The reasons for the reduction in shell dredging activity reflect both alternative raw materials and environmental concern. However, the overall USCE dredging activities as well as private dredging are expected to increase in the near future. Insufficient data are available on the extent of dredging and filling in the gulf coast, where it is a major environmental problem. Many of the environmental aspects of dredging are not well understood.

The federal permit system that deals with dredging activities in the coastal zone needs to be centralized and streamlined to expedite the efficient processing of permits. Environmental criteria used in evaluating USCE dredging permit applications should be clarified and quantified to the extent possible.

INTRODUCTION

The coastal zone constitutes one of our most valuable and vulnerable natural resources, an asset closely related to our national economy. As the economic value of the coastal zone rises and population pressure increases, the conflict between competing uses of the coastal zone becomes a complex problem. Today, we have almost six times as many people in the United States as we had a century ago. Since all of these people, in some fashion, call upon and derive some benefit from the coastal zone, the "nation has been forced to recognize that what it had in surplus, it now has in jeopardy" (Singer, 1969). Even seemingly unrelated uses of a coastal zone can have dire consequences; a solution to one irritating problem may engender far more pressing problems. For example, pesticides that help citrus growers in South Texas could result in fish kills in the Laguna Madre. While supertankers transport oil economically to all parts of the world, a massive oil spill can result in severe environmental damage. Modifications of estuaries through dredging operations, filling for real estate development, discharge of wastes from a city, fertilizer and pesticides in runoff from nearby land, are capable of disfiguring and destroying the coastal zone.

These estuarine systems are generally more fertile and productive of plant and animal life than either land or sea, due in part to the dynamics of the tidal cycle, which mixes incoming fresh water, with its nutrient burden from the land, with the mineral-rich water from the sea. Thus is formed a kind of rich broth fed by both the land and sea, resulting in a cradle of marine life. The estuary provides a sheltered environment for organisms which forms an abundant food supply for higher members of the food chain. Some estuaries are the spawning grounds and nurseries for many commercially important species. The United States Fish & Wildlife Service (Cain, 1968) estimated that approximately 90 percent of the total harvest of sea food taken by American fishermen comes from the continental shelf, and approximately two-thirds of the species involved depend in one way or another on estuaries.

In addition, estuaries serve other beneficial needs, such as important nesting and wintering habitat for migratory waterfowl, as well as resting and feeding places during migration. Estuaries also provide many forms of recreation to people who boat, camp, explore, picnic, nature walk, or merely enjoy the natural beauty of the coastal environs. Nowhere else do nature and urban conglomeration occur in such close proximity. Approximately 30 percent of

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the total population of the United States is located within a 50-mile coastal belt, while this area represents only about 8 percent of the total United States.

The U.S. Department of Commerce (1970) made an intensive study of the economic activity of the U.S. continental shelf for calendar year 1964. Eight major economic activities were identified: mining and petroleum; marine engineering; recreation; health and welfare; transportation; food and agriculture; defense and space; and research and development. The level of economic activity was estimated at $21.4 billion, a total that included operating expenses, investments, and income. A little more than half the money was spent for transportation activities; nearly $4 billion was spent for recreational activities; and about $330 million was the dockside value of the U.S. Fishery catch from the continental shelf area. The harvest of shellfish constituted the largest single portion of the U.S. Fishery catch value, about 38 percent. If the investment for harvesting and processing the entire U.S. Fishery catch for 1964 were included, then the total economic activity in fisheries increased to $1.4 billion, a very respectable industry (Singer, 1969).

A significant segment of the United States coastal zone is the gulf coast, from the Mexican border on the west to the tip of Florida on the east. This 1,500 miles of coastline constitutes the border of five states where they meet the Gulf of Mexico. The economic importance of this region is reflected in the commercial fishery production. In 1973, gulf coast landings represented 30 percent of the estimated $907 million in U.S. commercial fisheries landings. The value of commercial fisheries along the gulf coast has steadily increased in terms of both total poundage and dollar value (Table 1) as compared to other coastal areas of the U.S.

Approximately 85 percent of the gulf coast, as compared to like percentage of the Atlantic and 15 percent of the Pacific coast, is composed of estuaries (Singer, 1969). Gunter (1967) estimates that the total area of gulf coast estuaries ranges from approximately 17,000 to 20,000 square miles, or five to six times the size of Chesapeake Bay and its tributaries. The principal bays of the Gulf of Mexico are shown in Figure 1. "The National Estuarine Inventory, Handbook of Descriptors" (Wastler and de Guerrero, 1968) lists 39 primary estuarine systems in the Estuarine Register Areas and 175 secondary-tertiary systems along 3,670 miles of the shoreline.

Multiple utilization of gulf coast estuaries has resulted in significant modification and loss of valuable marsh and open water areas. "The National Estuary Study" (1970) determined the areas of gulf coast estuaries that had been modified by man's activities. Approximately 15 percent had been slightly, 51 percent moderately, and 34 percent severely modified by man's activities (see Figure 2). Unfortunately, many people do not realize the profound influence on the ecology of an estuary which can result from modifications in the watercourse. Oftentimes, even when they do understand the consequences, the short-term gain, rather than the overall or long-term effects, may be the overriding consideration for making such modifications.

Table 1.—U.S. commercial fisheries landings Gulf Coast Region compared to other major coastal regions.[1] (From U.S. Dept. Comm. 1970; 1973)

	1940	1950	1960	1970	1972	1973
	Total Poundage					
Percent	6%	12%	26%	35%	34%	33%
Rank	6th	3rd	2nd	1st	1st	1st
	Total Value					
Percent	11%	15%	24%	27%	32%	30%
Rank	3rd	3rd	1st	1st	1st	1st

[1] Chesapeake
South Atlantic
Gulf
Alaska
New England & Middle Atlantic
Washington & Oregon
California
Great Lakes & Mississippi River
Hawaii

DREDGING ACTIVITIES

One area of significant activity which results in modification of the coastal zone and its estuarine regions is dredging. Whether to provide channels for navigation or materials for construction, dredging operations can represent a substantial alteration to natural coastal environments. Moreover, the intensity of dredging activities in the coastal zone is anticipated to increase as a result of pressures such as exploration, drilling, and transportation in response to the energy crisis; the need for development of superports; increased demand for housing and commercial sites; and demands for additional coastal recreational facilities.

Dredging is the process by which sediments or other materials are removed from the bottom of streams, lakes, and coastal waters, transported by ship, barge, or pipeline, and/or discharged to land and/or open water. The common purposes of dredging are to maintain, improve, or create new navigable waterways, or to provide construction materials such as sand, gravel, or buried shell. In the majority of dredging operations, the solids are hydraulically transported from the bottom of the waterway to a dredge and then to a disposal site. This mixture of suspended solids and water is called dredge soil. It

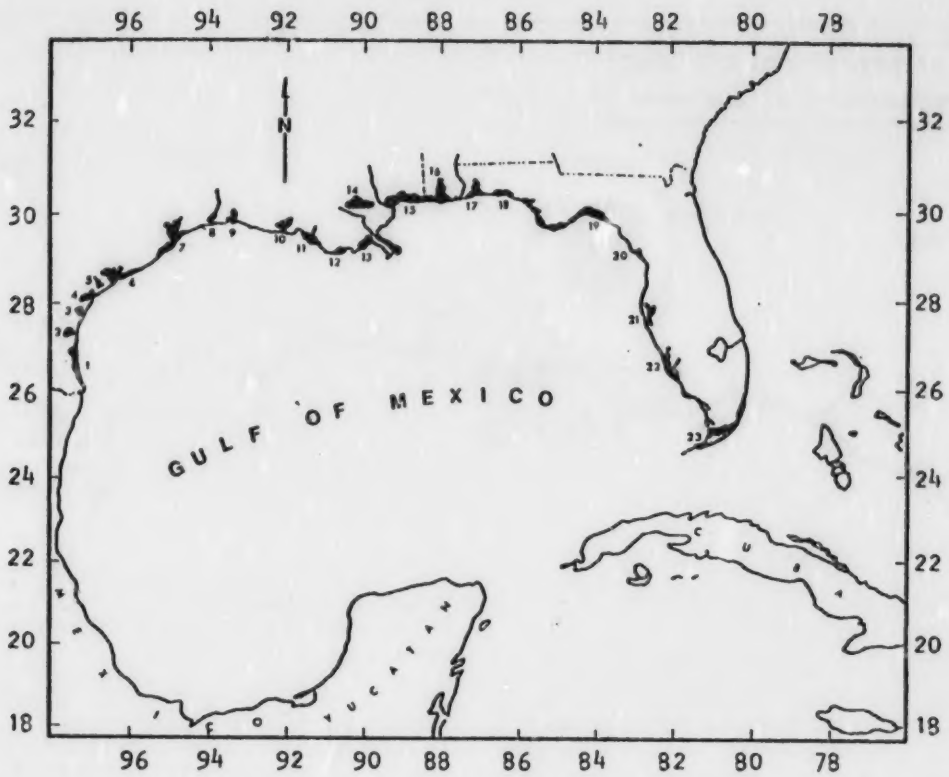

FIGURE 1.—Major bays of the gulf coast of the United States.

1. LAGUNA MADRE
2. BAFFIN BAY
3. CORPUS CHRISTI BAY
4. COPANO BAY
5. SAN ANTONIO BAY
6. MATAGORDA BAY
7. GALVESTON BAY
8. SABINE LAKE
9. CALCASIEU LAKE
10. VERMILLION LAKE
11. ATCHAFALAYA BAY
12. TERREBONNE BAY
13. BARATERIA BAY
14. LAKE PONTCHARTRAIN
15. MISSISSIPPI SOUND
16. MOBILE BAY
17. PENSACOLA BAY
18. CHOCTAWHATCHEE BAY
19. APALACHEE BAY
20. WACCASASSA BAY
21. TAMPA BAY
22. CHARLOTTE BAY
23. FLORIDA BAY

is typically about 5 to 20 percent solids by weight and 98 percent water by volume. The suspended solids vary in size from rather large rocks, bricks and debris (e.g. cans, tires, and steel cable) to extremely small particles of clay. When given the opportunity, the larger material quickly settles out of the water, but the smaller and lighter particles settle very slowly and dewater poorly. To protect the quality of the waterway, large volumes of spoil must be transported and then stored for some time in a disposal site before the water can be returned to the waterway. Transport and storage of spoil is expensive and difficult when the disposal site is of insufficient size or near capacity. Moreover, in urban areas adequate disposal sites are becoming increasingly difficult to acquire.

Types of Dredges

In general, dredging in the coastal zone is accomplished by "floating dredges" which can be classified as hydraulic or mechanical. Hydraulic dredges include suction pipeline dredges, with a suction or cutterhead for digging in hard material, and the self-propelled hopper dredge. Mechanical types include dipper and bucket dredges. Hydraulic channel dredging and shell dredging make use of essentially the same equipment although there are differences in operations. Channel dredges construct or maintain navigation channels. In this operation, recent alluvium and water are pumped from the bottom of the channel and the spoil is discharged by pipeline usually some distance away from the channel. Shell

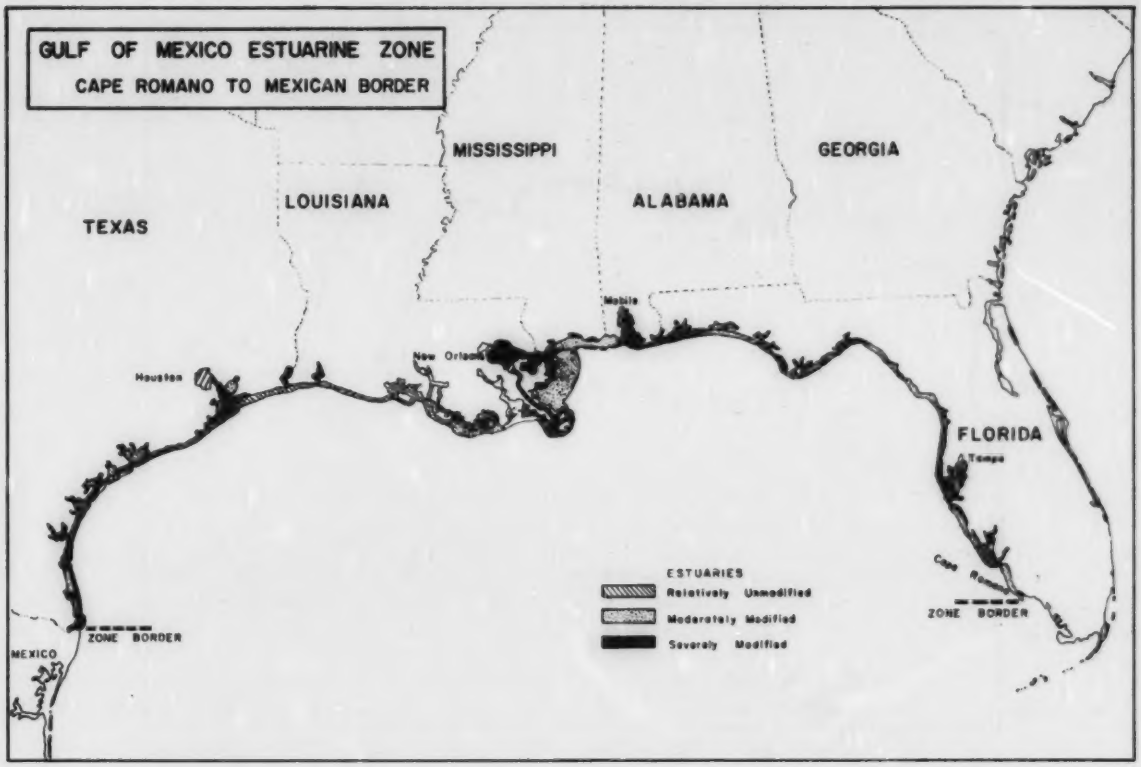

FIGURE 2.—Extent of effects of man's activities on gulf coast estuaries (from "National Estuary Study," 1970).

dredges generally operate outside of channels in the open estuary. Dredged material is screened and washed to remove the shell. The discharge, composed mostly of original bottom material is returned overboard in the immediate vicinity of the dredge.

Required Dredging Permits

The basic permit that is required for dredging activities in the coastal zone is under Section 10 of the River and Harbors Act of 1899, which is administered by the United States Corps of Engineers (USCE). This permit is required when any dredging or filling is done in navigable waters of the United States or in areas which may affect navigable waters. New Federal guidelines (Federal Register, April 3, 1974) require that the environmental aspects of these dredging permits be considered. In addition, the Environmental Protection Agency requires permits under Section 404 of the Federal Water Pollution Control Act Amendments of 1972 for the discharge of dredged or filled material. In each of the federal permits, review and approval is required from various state agencies. Also, along the gulf coast, each state requires permits for dredging in the coastal zone. As a result of the 404 dredging permit system, considerable questions have arisen with regards to its relationship with the existing Section 10 permit system. These questions concern jurisdiction as well as specific engineering and environmental requirements. The present Section 10 permit system, because of other federal agency review in many cases, results in considerable time and money being expended by the applicant because of the time delay and lack of coordination.

Shell Dredging

Buried shell is an important natural resource found in the coastal zone. Industrial demand for this almost pure source of calcium carbonate is significant and several major industries depend upon it. Private companies annually dredge about $30 million worth of unprocessed clam and oyster shells from gulf coast estuaries and the resource makes a substantial contribution to the economy of many coastal areas.

Table 2.—Shell production in cubic yards by State (1965-74)

	Florida (Jan. 1–Dec. 31)	Alabama (Oct. 1–Sept. 30)	Mississippi	Louisiana (Jan. 1–Dec. 31)	Texas (Sept. 1–Aug. 31)	Total
1965	1,675,557	1,972,499	208,222	N/A	N/A	N/A
1966	1,796,561	1,842,737	187,028	8,681,177	11,702,553	24,210,056
1967	1,492,102	1,766,611	206,333	9,500,285	12,512,977	25,478,308
1968	1,102,052	1,867,794	228,183	10,921,101	10,033,221	24,152,351
1969	1,949,668	N/A	119,662	10,097,148	9,108,682	22,975,160**
1970	1,480,472	N/A	165,144	10,283,276	9,097,316	22,726,208**
1971	1,539,299	1,685,445	135,008	10,901,371	8,198,153	22,459,276
1972	1,611,403	1,543,217	281,129	11,708,035	7,791,577	22,935,361
1973	1,046,988	1,275,603	339,513	11,996,579	7,444,232	22,102,915
1974	325,806*	1,608,997	98,033	N/A	7,027,909	N/A

* Five months only.
** Estimated 1,700,000 for Alabama.
Florida—William Witfield, Florida Department of Natural Resources, Division of Marine Resources and Jack Dull, Fiscal Office, pers comm, Nov. 1974
Alabama—Mr. Swingle, Alabama Department of Conservation and Natural Resources, Marine Resources Division; Revenue Department, pers comm, Nov. 1974; May, 1971
Mississippi—Mr. Quinn, Mississippi Marine Conservation Commission, pers comm Nov. 1974.
Louisiana—Joseph Cuadrado, Louisiana Wildlife and Fish; Revenue Department, pers comm, Nov. 1974
Texas—Chester Harris, Texas Parks and Wildlife Department; Revenue Division, pers comm, Nov. 1974

In addition, royalty from shell dredging contributes about $3 million each year to conservation activities in the gulf states (May, 1971). Shells from this source are extensively used for cultch (attachment material for new oysters) on public oyster beds in many states and the practice has greatly increased oyster production.

Along the gulf coast shell dredging is a major industry. Most of the shell is used for manufacture of cement, masonry blocks, road materials, poultry feed, and in some cases for the creation or establishment of oyster beds. Summarized in Table 2 are shell production figures for each of the gulf coast states as determined from published records and by personal communications with various state agencies. The total production for the gulf coast for the period 1966 through 1973 shows a slight downward trend. In Mississippi shell production has recently been stopped. In Texas (along with Louisiana, the major producer) shell production has been declining. In Texas, production has shifted from the Galveston Bay area to Matagorda and San Antonio Bays (see Figure 3). The change from the Galveston Bay system to Matagorda Bay is a result of changes in Texas Parks and Wildlife dredging policies coupled with significant reductions in the shell reserve in Galveston Bay.

Extent of USCE Dredging Activities

The majority of dredging activities in the coastal zone is accomplished by the U.S. Corps of Engineers in the development and maintenance of navigable waters. Within this authority, the USCE is responsible for the dredging of a large volume of material in the gulf coast each year. Boyd, et al. (1972) present a compilation of data on the magnitude of dredging operations. It is important to note that this data does not reflect dredging activities of other agencies or private industry under the permit program administered by the USCE. The majority of the dredging operations in connection with USCE projects are done by pipeline and hopper dredgers. The USCE is responsible for dredging and maintain-

FIGURE 3.—Percentage of shell production in the State of Texas for major bays by year (from Eifler, 1968 and Texas Parks & Wildlife, Revenue Division, 1974).

Year	Sabine Lake	Galveston	Matagorda	San Antonio	Lavaca	Nueces
1965-66	1.4	62.8	0	23.7	1.6	11.0
66-67	2.1	62.2	0	24.5	1.8	9.4
67-68	0.1	41.7	0	42.8	5.8	9.6
68-69	0.2	4.9	0	80.5	6.1	8.4
69-70	0.9	0.9	11.2	81.5	0.2	5.4
70-71	0.6	0	24.8	69.1	0	5.6
71-72	0	0	33.8	59.9	0	6.4
72-73	0	0	41.3	51.0	0	7.8
73-74	0	0	62.8	34.0	0	3.3

ing approximately 4,000 miles of navigation channels on the gulf coast. Gulf coast dredging represents historically 48 percent of all USCE dredging activities. Total dredge spoil generated in maintenance dredging annually averages 143.0 million cubic yards. Average quantities of spoil for each Corps of Engineers District in the gulf coast is shown by disposal type in Table 3.

The USCE (Boyd, et al., 1972) estimated that approximately 177.6 million cubic yards of spoil material would be dredged in 1972 in the gulf coast zone, of which 55.2 million cubic yards would be new work. Of these activities 61 percent of the dredging was proposed in the New Orleans District, 26 percent in the Galveston District, 11 percent in the Mobile District and 2 percent in the Jacksonville District.

ENVIRONMENTAL ASPECTS

A variety of studies (Masch and Espey, 1967; Chapman, 1968; May, 1973; Cronin et al., 1970; U.S. Army Corps of Engineers, 1974) describe the environmental aspects of shell dredging, channelization, and spoil disposal. Unfortunately, the impact of these operations on the gulf coast ecosystem is incompletely known. However, enough is known about the ecology of estuarine systems to evaluate, in general, the major ecological consequences involved. Figure 4 is a generalized flow chart which diagrams the manner in which ecology is affected by dredging. Three main categories resulting in four principal pathways are involved. This is a simplification of the complex interactions which actually occur. However, some of the other more obscure interactions form pathways which may or may not occur in a particular system, or are poorly understood. Attention given them would only serve to confuse the basic cause and effect relationships.

The following subsection will deal with the primary effects of dredging separately.

TABLE 3.—Average Quantity of Spoil Material (million cubic yards) Dredged in the Gulf Coast by Disposal Method and District*

	Galveston	*New Orleans*	*Mobile*	*Jacksonville*
Undifferentiated†	18.2	None	13.6	None
Confined	8.7	20.3	2.5	0.2
Open Water	21.0	40.5	13.7	2.5
Upland	None	None	0.4	1.4

* From Boyd, et al. (1972)
† Disposal Method Not Defined

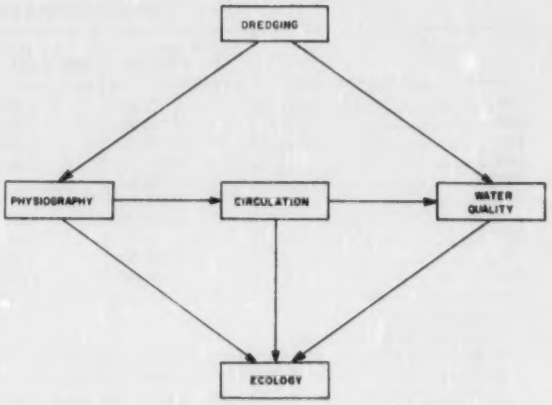

FIGURE 4.—Environmental aspects of dredging.

Physiography

All dredging operations involve the physical modification of the environment by removal of bottom material and its disposal. Such actions result in the loss of habitat for benthic organisms, including oysters and a multitude of other creatures of significant value in the food chain. The extent of the area in the gulf coastal zone which has been impacted by dredging is difficult or impossible to determine.

Table 4 is a compilation of data from the various segments of the Cooperative Gulf of Mexico Estuarine Inventory and Study for the Gulf States, and Chapman (1968). Historically, Cain (1967), Chapman (1968), and the "National Estuarine Study" (1970), have all estimated the amount of estuarine habitat and acreage modified. The inconsistencies in the acreage values listed from one report to another are based primarily on the use of differing criteria in defining the limits of estuarine areas, period of record, and incomplete data. The latest total estuarine acreage value is 13,898,978 acres taken from Table 4. The NES (1970) lists 655,900 acres of important habitat that had been lost to dredging and filling for the period 1950 to 1969.

Due to siltation, dredged areas usually require periodic maintenance dredging which disturbs any recolonization by benthic organisms which may have occurred. In many channels, however, the substrate stabilizes enough to allow the establishment of a benthic community.

It is important to note that some estuarine areas are more valuable than others. Thus a simple acreage figure of dredged areas may not tell the entire story. Areas of submerged aquatic vegetation (turtle grass, widgeon grass), emergent marsh grass areas (salt-

Table 4.—Alteration of estuarine areas in the Gulf Coast Zone (acres)

	Florida[1] (West Coast)	Alabama[2]	Mississippi[3]	Louisiana[4]	Texas[5]
Total					
Estuarine area	3,003,213	431,967	500,380	7,289,568	2,673,830
Tidal marsh	921,688	34,614	66,933	3,910,644	1,141,400
Open water	2,081,525	397,353	433,447	3,378,924	1,532,430
Alteration					
Emergent spoil banks	1,135	17	9,000†**	25,369	—
Filled causeways	3,977	76	—	—	—
Housing, industry, and other	18,409	2,059	—	1,246	—
Drained tidal marsh	26,676	—	—	47,792	—
Spoil area	—	—	—	40,000	78,500[6]
Miles of Corps of Engineers channel	1,500†	144	300†	1,000† (4,572.6*)	990
Surface area of Corps channels	—	3,420	—	— (42,104*)	20,260[6]

[1] McNulty, Lindall, and Sykes, 1972.
[2] Christmas, 1973.
[3] Crance, 1971.
[4] Perret, et al., 1971.
[5] Diener, R. A., 1974.
[6] Chapman, 1968.
* Estimate of total length and area of channels and canals in Louisiana.
** All filled areas combined.
† Approximate.

marsh, cordgrass), mangrove swamps, and shell reefs all rank higher in ecological value and sensitivity than do soft open bay bottoms. Estuarine areas are centers of production for many commercially or recreationally important species and for the organisms on which they depend for food. Measures must be taken to perpetually protect such areas from destruction. Indeed, a worthwhile endeavor is the creation of new habitat, e.g., marshland areas, when possible. The feasibility of such procedures is discussed by Woodhouse (1972).

Another area of concern is the loss of habitat through sedimentation. The dredging processes suspend part (1 percent according to Mackin, 1962) of the dredged material into the water column. The resulting suspension forms a plume of turbid water at the surface and turbidity currents along the bottom. Masch and Espey (1967) noted that, while shell dredging does not introduce sediments into the bay water, the dredging does resuspend materials already present on the bay bottom. The suspended sediment load in the vicinity of even a single dredge is at least an order of magnitude greater than the suspended load produced by currents, strong wind and wave action, ship and barge traffic, and ship swells in Galveston Bay, Tex. The levels of nitrates and phosphates in the immediate vicinity of the dredge were 50 to 1,000 times greater than the ambient levels; however, no detectable effects on photosynthesis of plankton were noted (Cronin, 1970).

Masch and Espey (1967), O'Neal and Sceva (1971), and May (1973) have all delineated density flows of sediment along the bay bottom associated with dredging operations. These turbidity currents seem to be principally affected by tidal currents, bottom sediments, topography and dredge discharge characteristics. The hydrodynamics of these currents are not well understood; however, they can cover broad areas of bay bottom before flocculating out, thus substantially reducing benthic populations by smothering them. Studies of the effect of shell dredging on live oyster populations have shown these turbidity currents are capable of covering and smothering live reefs. The U.S. Army Corps of Engineers (1974) in San Antonio Bay, Tex., showed that although nektonic organisms easily escaped turbidity flows, sessile benthic populations were adversely affected. While deposition of spoil on bay bottoms and in dredge cuts substantially reduces benthic populations over time periods ranging from several months to several years, these populations, if undisturbed, slowly recover.

Circulation

Current Pattern and Speed Alteration

Within this category are the effects of density currents and topographic changes which modify both the current pattern and speed. Many of the migratory species (e.g., white and brown shrimp, crabs, various fish) utilizing the estuaries are dependent on salinity for their navigation. The stable long-term density gradients (in salinity) set up by

a dredged canal could possibly redirect the migratory route of species and potentially negatively impact the standing crop of those organisms.

Topographic changes associated with dredging can affect current velocities. Such changes can alter the distribution of current-dependent plankton organisms. Where current velocity is significantly reduced, established pathways for the distribution of planktonic organisms may be blocked. Also, increased sedimentation associated with velocity alterations may smother benthic populations and reduce the suitability of the substrate for such populations. Kutkuhn (1966) notes that, because of new circulation and water quality regimes, the creation of "fish passes" may increase the ecological carrying capacity of an area.

Water Quality

Water quality parameters fall into two categories, physical and chemical. Factors such as turbidity, light penetration, and temperature are important physical parameters, while salinity, nutrient loading, dissolved oxygen, and toxic substances are chemical parameters.

PHYSICAL PARAMETERS

Increased turbidity is one of the more noticeable short-term effects of dredging. This was discussed in the physiography section, where it was pointed out that while nekton and plankton can escape from turbidity plumes, benthic organisms are negatively impacted by the settling out of the suspended solids. Reduced light penetration (euphotic zone) due to turbidity plumes is documented by Sherk (1971).

Odum and Wilson (1962) state that "the turbid mixtures of organic and inorganic matter both interfere with photosynthesis and stimulate it by indirectly raising inorganic nutrient levels." Depending on location, dredge spoil may or may not contain nutrients. It is important to note that estuarine productivity is primarily dependent upon organic and inorganic nutrient loading from the rivers and marshes emptying into them rather than upon local photosynthesis. Thus turbidity does not impact estuarine production to the extent that it would in a system having phytoplankton as the primary base of the food web. In addition, these effects are transient, being in evidence only during the actual operation of the dredge. Over longer periods of time, some increase in turbidity may occur in the vicinity of spoil banks. This is possible because the decreased depth of water over these areas may facilitate stirring of soft bottom materials by current and wave action.

Temperature changes as a result of dredging operations are probably relatively unimportant to the estuarine ecosystem when compared to those in other physicochemical parameters. Most gulf coast estuaries are shallow bodies of water which are not thermally stratified. Deep dredged channels represent an area where stratification can occur. The ability of a deep water mass to resist very rapid temperature changes associated with winter storms known as "northers" occasionally prevents fish kills, which sometimes occur in the shallow bays of Texas (Gunter, 1941; Gunter and Hildebrand, 1951), by providing a thermally stable haven for fish.

CHEMICAL PARAMETERS

Salinity is a critical chemical parameter potentially affected by dredging activities. The distribution of many species within an estuary is closely tied to the salinity pattern. In the case of many species (e.g., blue crab, brown and white shrimp), the distribution of various stages in the life cycle is tied to different salinity levels. In some instances the intrusion of more saline water due to channelization may not be extremely detrimental; however, in general, increasing salinity intrusion reduces the necessary low and mid-range salinity areas required for the development of juveniles of many estuarine species. Salinity wedges moving up and down channels depending on freshwater inflow prevent the establishment of a stable benthal community.

The salinity pattern of an estuary can be impacted by deep channels through the formation of density gradients. Such gradients are long-term phenomena which provide a series of decreasing isohalines as the distance from the channel increases. Migratory routes of animals such as shrimp might well be interfered with by these density gradients.

Due to sorption and ionic processes bay sediments represent effective traps for a wide variety of potentially hazardous industrial and natural chemicals. Dredging and spoil deposition may release many such substances (e.g., herbicides, pesticides and heavy metals) into the aquatic ecosystem. Lee and Plum (1974) describe an elutriate test designed by the USCE and the EPA to detect the release of chemical contaminants in dredged materials into the water column.

Deeper channels often display anoxic conditions due to benthal oxygen demand. Dredging in recreational developments with dead end canals with depths of over five to six feet often produces stagnant conditions because of poor water circulation, low

light penetration and high nutrient loading. Such conditions often foster plankton blooms which ultimately raise biological oxygen demands and sometimes produce fish kills.

CONCLUSIONS

The following is a summary of major conclusions.

1. Eighty-five percent of the Gulf of Mexico estuaries between Cape Romano, Fla. and Brownsville, Tex., has been moderately or severely modified by man's activities.

2. The energy crisis and the resulting increased oil exploration, production, and transportation activities further threaten the environment of the coastal zone.

3. Important estuarine habitats have been destroyed by dredging and/or filling.

4. Approximately 48 percent of U.S. Corps of Engineers dredging activities occur along the gulf coast.

5. Insufficient data is available on the extent of dredging and filling operations in the gulf coast for both the Corps of Engineers and private industries.

6. Shell dredging production data indicates a slight reduction in the gulf coast zone for the period 1966–1973.

7. Texas shell production for the period 1966–1974 indicates an approximate 40 percent reduction.

8. The direct overboard disposal of washwater from shell dredging operations is a major environmental problem.

9. Additional information is required on the release of chemicals from bottom sediments as a result of dredging activities.

10. Environmentally acceptable spoil areas should be identified in major estuarine areas.

11. Additional information is also needed on the movement and fate of sediments suspended by dredging activities.

12. Salinity is a critical chemical parameter potentially affected by dredging activities. However, insufficient information is available on the effect of channel dredging and spoil deposition on salinity modifications.

13. The Dredged Material Research Program of the USCE should provide additional information on the environmental aspects of dredging in the coastal zone.

14. Clarification of environmental criteria used in the evaluation of USCE dredging permits is needed.

15. Streamlining and centralization of the federal permit system is required for dredging activities in the coastal zone.

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NUTRIENTS

NUTRIENT LOADING IN THE NATION'S ESTUARIES

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ABSTRACT

An evaluation is made of the current status of nutrient loading in the nation's estuaries. Special consideration is given to sources and transport of nutrients and their impact on estuarine ecosystems. Critical problems and trends in nutrient loading are reviewed at the national level and for six major estuaries: Cook Inlet, Columbia River Estuary, San Francisco Bay, Galveston Bay, Pamlico Sound and Chesapeake Bay.

INTRODUCTION

Estuaries and their transition zones comprise 27,000,000 acres in the United States (Congress, 1970) and are annually responsible for more than 65 percent of America's fish and shellfish harvest (Smith, Massmann and Swartz, 1966). An estuary is a unique zone in coastal environments in which fresh water from rivers mixes with salt water from the ocean. It is a complex interacting system in delicate balance among the physical, chemical, and biological forces present at any particular time.

An estuary is a nutrient storehouse; marshes and wetlands are constantly flushed of decomposing plant material by tides. These nutrients are transported into the estuary and support a substantial production of biomass. A Georgia salt marsh for example contains enough nutrient reserve to permit optimum ecosystem functioning for 500 years without renewal (Clark, 1974). The enriched soils of estuaries are often several feet thick and are held together by extensive plant root systems. This natural ageless phenomenon can continue as long as the system is not modified by the impact of human activities. "The National Estuary Study" (1970) reports that all of the nation's estuaries have been modified: 23 percent severely, 50 percent moderately and 27 percent slightly. One of the major impacts has been increased nutrient loading.

Nitrogen, phosphorus and organic carbon are the major components of nutrient loading; their transition is cyclic, resulting in effects which are cumulative and compounded (Woodwell, 1970). A major result of nutrient overenrichment is eutrophication which is the normal environmental aging process. Eutrophication is the buildup of rapidly cycled organic carbon. Early signs are excessive growth by phytoplankton or vascular plants, and a reduction in species diversity. Nutrient loading is a relative state in which low and high levels produce undesirable conditions: high levels stimulate eutrophication while low levels limit productivity. The optimum nutrient load is a mid level in which the estuarine system reaches stability in both productivity and diversity. The optimum nutrient loading will vary with each estuary due to the natural accumulative capacity of each system. In all cases, the limiting nutrient controls the total potential development.

The health of an ecosystem is directly proportional to the species diversity of that system over an extended period of time. A healthy system exhibits many species of phytoplankton, each of which has a particular dominance period followed by its return to background levels, with other species blooming at their selected times when environmental conditions dictate. This natural cycle permits many different algal species to coexist and compete against one another while the entire system remains in careful balance. Under natural conditions, these blooms will occur regularly, each with an associated assemblage of zooplankton, invertebrates and fish larvae within the estuary. Many species prey on selected plankton forms and have evolved mechanisms of timing stages of embryonic development to follow specific plankton blooms. It is this type of mechanism that characterizes a healthy aquatic ecosystem and permits it to function with a high rate of productivity year after year. Excessive nutrient loading supports the bloom of one or more species which are particularly favored and/or tolerant of the added nutrients. Those species which succeed under these conditions are usually not preferred components of food webs, and total fisheries productions are reduced. The result is an unbalanced system, low in species diversity due simply to the selective fertilization of undesirable phytoplankton.

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NUTRIENT SOURCES AND TRANSPORT

Municipal Sewage and Industrial Waste Discharges

The major contributors of nutrient sources are municipal sewage and industrial waste discharges, urban runoff, agricultural and forestry practices. In the coastal zone, most nutrients are terrigenous and are transported toward the ocean with river flow. In some estuarine zones, it is even possible for nutrients to be transported up river by floodtide (Ketchum, 1969). Therefore, an area of an estuary cannot be considered immune to a nutrient source located below it.

The flushing of nutrients from an estuary is a function of the volume and flow rate of the water source in addition to the physical topography of the water basin. If the freshwater source is of great magnitude, as in the case of the Columbia River in Washington, the residence time of water mass may be very short, meaning that nutrients do not have enough time to exert their effects upon the system. If, on the other hand, the freshwater flow rate is slow (Pamlico River Estuary), the flushing action is reduced and the system is unable to rapidly export nutrients, therefore allowing them time to exert more influence on the system. For this reason, estuaries differ greatly in their tolerances of nutrient loading.

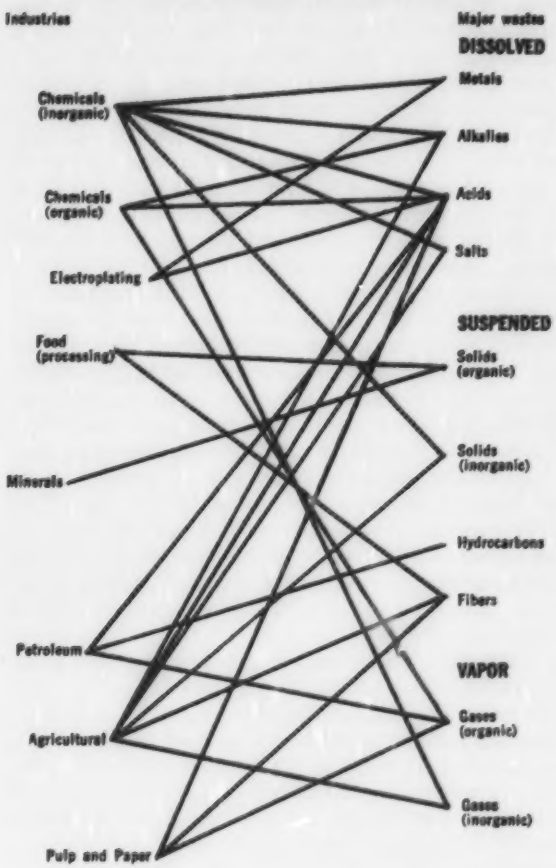
Thousands of municipalities dump sewage treated to various degrees into inland waterways flowing towards the sea. A great number of inland coastal cities were founded on rivers for a variety of reasons, but among them was the availability of municipal and industrial waste disposal into the waterways. This practice has continued today. Even though the cities have grown to tremendous sizes, these rivers are expected to transport greatly expanded volumes of waste downstream to be rendered innocuous by natural processes, even though the average annual riverflows remain approximately the same. Municipal sewage has its origins in plant and animal wastes; therefore, it is an enriched mixture of nitrogen, phosphorus and carbon compounds which provide the essentials necessary for plant growth. This growth (primary production) is consumed in turn by microorganisms, protozoa, rotifers, zooplankton, crustaceans and so on up the food chain, stimulating species diversity and stability in the system. Pollution of the stream by sewage treatment effluents and runoff from fertilized lawns has caused the State of Florida to place restrictions on recreational activities there, after seeing the harmful effects exemplified by a number of fish kills between 1970 and 1973.

Unregulated construction in urban areas increases the amount of sediment and nutrient transport into estuaries by freshwater runoff from the land. Simple construction like paving significantly increases the sediment loading. Dredging activities, bridge-building and resort land developments tend to resuspend the sediments containing nutrients, organic particles, trace elements, and toxic substances in estuaries.

Public Law 92-500 requires that point source dischargers (industries, municipal treatment plants, feedlots, and other discrete sources) must obtain permits requiring that such discharges meet all applicable requirements relating to effluent limitations as regulated by the Environmental Protection Agency. This effort to regulate what enters the nation's waters represents an attempt on the part of the government to not only limit nutrient input but also the thousands of other chemicals discharged daily with little if any treatment. States which desire to administer the national permit program may submit complete program descriptions to the Administrator for approval with the stipulation that all individual permits are subject to EPA review, and annually the states must submit reports to EPA that inventory all point sources of pollution and assess existing and anticipated water quality. This National Pollution Discharge Elimination System (NPDES) provides EPA with the authority to enforce the effluent limitations and allows private citizens or groups to levy judicial process against any polluter in violation of an effluent limitation or administrative order.

Industrial and commercial wastes provide a further nutrient source to estuaries. Industry has been accredited with contributing over 60 percent of all U.S. water pollution (Nobile and Deedy, 1972). The principal industrial offenders are by category: paper, organic chemicals, petroleum and steel. Much of the conventional technology used in municipal waste water treatment is used also to treat industrial wastes. Existing data suggest that about half the total volume of waste water treated by municipal plants is of industrial origin. The current trend appears to be toward more joint use of treatment plants by industry and municipalities. It is also difficult to generalize on treatment of industrial waste waters because the sources are highly diverse. Industrial waste waters generally are less amenable to conventional waste treatment because they contain substances such as trace metals and chemical compounds that resist biological degradation. Also, to reduce discharges, industry has increased its reuse of water, partly to reduce the costs of pollution abatement and stay within federal regulations pertaining to discharges. Today, industry probably reuses an average of three gallons of water for every new gallon it takes in.

Table 1.—INDUSTRIAL SOURCES OF NUTRIENT LOADING



Modified from Nobile and Deedy (1972).

Most industrial discharges contain high oxygen-demand wastes or toxic materials; however, a large portion of industrial discharges contain some form of available nutrients. Most contain some form of carbon (inorganic or organic). Then there are special industries which produce some form of nitrogen or phosphorus either as an intermediate byproduct or a waste product (i.e., fertilizer manufacturing or phosphate mining, cattle feed lot operations). In farming operations, the fertilizer is applied to increase production and a portion leaches out and is carried away in runoff. The major industries and their major wastes are given in Table 1.

Another important industrial waste as a source of nutrients is the food processing industry. Most of these discharges are processing wastes and are discharged into rivers from the canneries. However, commercial fishery industries have a unique waste that is discharged directly into the estuary; for instance: one third of a salmon's weight is considered to be waste and Alaska salmon canneries annually dump more than 100 million pounds of this waste into estuaries. Some of this fish is used as mink food but the vast majority is dumped into coastal waters. The decomposing fish waste contributes to the nutrient loading and greatly influences species diversity and can increase selected species populations. In Alamitos Bay, Calif., very polluted bottom areas are found which are surrounded by a thick sediment of fish scales containing unnatural populations of red annelid worms (*Capitella capitata*) in concentrations as high as 6,000 per square meter. In 1963 it was reported that several Texas harbors were receiving shrimp and crab wastes, raising the phosphorus concentration from 0.049 mg/L to 0.143 mg/L (Odum, et. al., 1974). Such dumping not only represents an additional nutrient source but it enters in such forms as protein and fat at irregular intervals. The abundance of nutrients favors organisms which expend less metabolic energy and gives advantage to forms which can use organic breakdown products at the early stages of their decomposition cycle. For instance, species capable of utilizing ammonia as a nitrogen source are usually tolerant to high levels and survive better than those organisms requiring it oxidized to nitrate.

Pulp and paper mills have long been known for their pollution effects in rivers. The waste produced by their processes exerts an immediate oxygen demand upon the water their effluent enters. This is caused by the chemical demand for oxygen made by the SO_2 which depletes the dissolved oxygen present in the water. Studies of the York River, Va., indicate that sulfate wastes inhibit oysters from efficiently metabolizing carbohydrates. The volume of water filtered by the oysters was also reduced but increased as they were removed from the waste water. (Odum, et. al., 1974)

Urban Runoff

Vitale and Sprey (1974) have reported that between 40 and 80 percent of the total annual BOD and COD entering receiving waters from a city is caused by sources other than the treatment plant. They also report that 94 to 99 percent of the total BOD and COD load from a single storm event is contributed by sewer overflows, storm sewers, runoff and bypasses, and that the periodic loads from storm events exert a demand which is 40 to 200 times greater than that of the normal dry

weather effluent from the sewage treatment plant. In their study they found that the storm water annual contribution of nutrients (nitrogen and phosphorus) appears to be generally less than 10 percent; however, storm water nutrients dominate all other sources during a storm event.

ESTUARINE NUTRIENT CYCLES

A better understanding of the cycling of nutrients in estuaries would greatly contribute to man's ability to increase the yield of coastal fisheries. Already estuaries are considered among the most productive aquatic areas in the world and their importance continues to grow with the world's growing populations.

Estuarine ecosystems differ from freshwater and marine ecosystems by their relatively high concentrations of nutrients. These nutrients enter the estuary from river nutrient loading and the decay of marsh vegetation and are trapped by physical, chemical and biological processes. The large quantities of nutrients trapped in the estuary promote a high rate of plant production. This plant biomass is very important because the animals in an estuary are directly or indirectly dependent upon plant material as an energy source. Plant tissues are composed of the following principal elements in descending order by weight: oxygen, carbon, hydrogen, potassium, sodium, calcium, sulfur, chlorine, phosphorus, and magnesium. Certain necessary trace elements include silicon, iron, manganese, and zinc. Much current literature indicates that in coastal waterways, nitrogen and phosphorus compounds have been reported to be the limiting factors for plant growth.

Nitrogenous Compounds

Nitrogen represents the fourth most abundant element by weight present in plant tissues and one of the two generally considered to be limiting in aquatic production. Clark (1974) reports that in coastal waters the amount of available nitrate is generally believed to be the nutrient factor that controls the abundance of plants. Municipal sewage disposal into rivers and estuaries is the major contributor of nitrogen compounds in the estuarine systems. Nitrogen naturally occurs in these forms: ammonium ion-NH_4^+, ammonia-NH_3, nitrite-NO_2^-, the nitrate ion-NO_3^-, molecular nitrogen-N_2, and complex organic nitrogen complexes. A simplified estuarine nitrogen cycle is given in Figure 1, which has been modified from Odum, 1971.

In the atmosphere, most of the nitrogen present is in the form of N_2 with lesser amounts of ammonia, and oxides of nitrogen derived from the combustion of fossil fuels. Atmospheric ammonia originates from a number of sources including air pollution, photochemical reactions of the stratosphere, and the decay of plant and animal byproducts. Rainfall acts to rinse the air, bringing this vast array of nitrogeneous products into aquatic systems. Only a few algal and bacterial species are able to utilize molecular nitrogen (N_2) for their nitrogen requirements. Ammonia is oxidized into nitrites (NO_2^-) by nitrifying bacteria, which is further converted to nitrate (NO_3^-) using the reaction as an energy source and making the product more available to plants. Most plants use ammonia, nitrate, or nitrite in the production of proteins and nitrogeneous nucleic acid components. This is an important interconversion of inorganic nitrogen to organic nitrogen. Animals, being unable to make this interconversion, are entirely dependent on plants. In decomposition, biological processes convert organic nitrogen to ammonia, nitrite, and nitrate for recycling. The refractory organic forms are resistant to decomposition and may remain for years in the system (Williams, 1971).

Photosynthesis assimilates inorganic and organic nutrients, most of which are present in excessive amounts. However, nitrogen naturally occurs in micromolar concentrations which can be completely assimilated from the water mass by phytoplankton of a given area. The major unnatural sources of nitrogen in an estuary are: municipal and industrial wastes, fertilizers from agricultural and forestry practices, and urban runoff. In estuaries where nitrogen is limiting, these wastes accelerate eutrophication. EPA criteria (1973) recommended prevention of any nutrient discharge causing enrichment leading to any major change in the natural levels of flora. However, there are no EPA standards regarding nutrient loading for "maximum acceptable concentrations" of nitrogen and its compounds (Proposed Criteria for Water Quality, EPA, 1973).

Phosphorus Compounds

Nitrogen and phosphorus represent the two elements generally found to be limiting in natural systems; however, nitrogen is generally considered to be the more important of the two. Ryther and Dunstan (1971) suggest that since phosphate is normally present in concentrations twice that of nitrogen in the coastal marine environment, nitrogen must be the critical limiting factor. The "maximum acceptable concentration" for phosphorus is placed

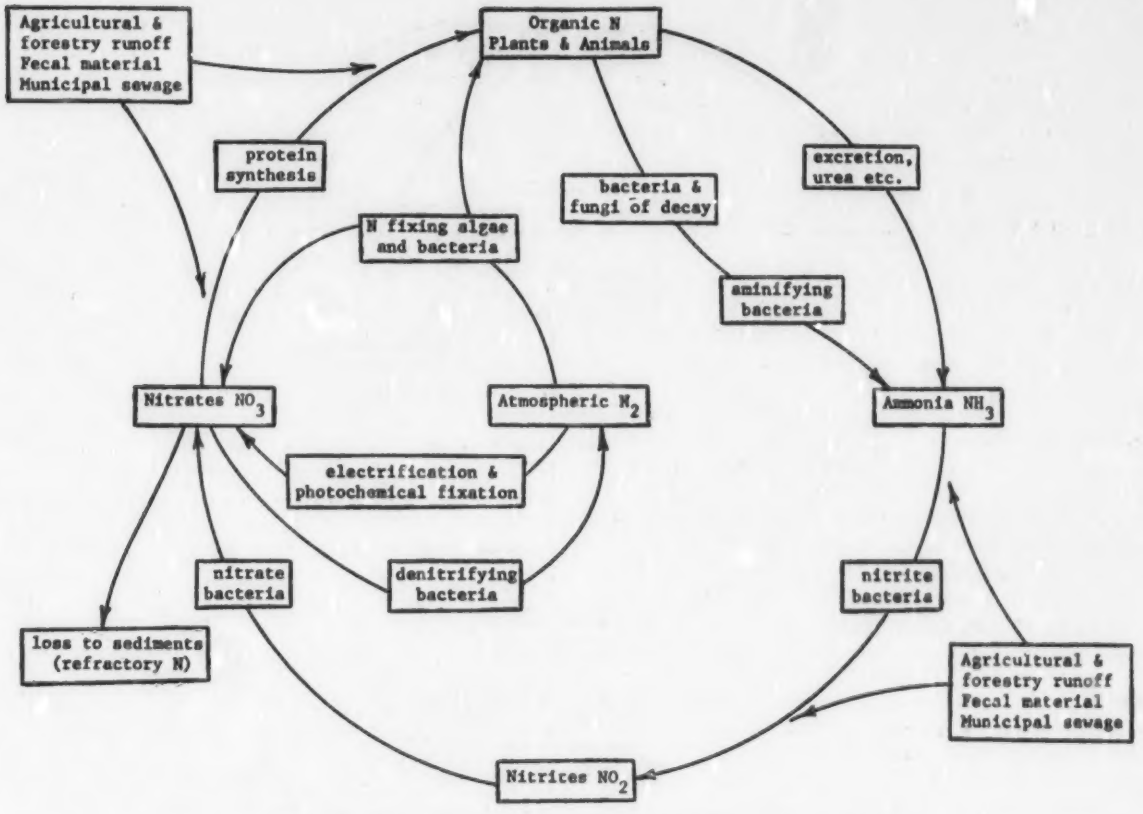


FIGURE 1.—The estuarine nitrogen cycle (modified from Odum, 1971).

as 100 mg/L with no "minimum risk threshold" value given (EPA, 1973).

Phosphorus exists in a great number of forms, the most prevalent of which is the phosphate group PO_4. A simplified estuarine phosphate cycle is given in Figure 2, which has been modified from Odum, 1971.

The slightly soluble inorganic phosphorus of the earth's crust is an unlimited reservoir which slowly leaches into aquatic systems through the weathering of rock. These soluble orthophosphates are quickly assimilated by plants and transformed into particulate organic phosphorus. Dissolved inorganic phosphorus compounds are released into solution by excretion or decomposition and are transformed into particulate organic phosphorus, or through degradation are converted back to inorganic orthophosphates. As in nitrogeneous forms, some of the organic products result in refractory compounds, unavailable for biological use and become part of the sediments.

Manmade detergents contain phosphates similar to those produced by living organisms. If phosphates in detergents are replaced by nitriloacetic acid (NTA), a nitrogen compound as is, the current trend in industry, the net effect could be the acceleration of eutrophication (Ryther and Dunstan, 1971). These authors also estimate that 25–50 percent of the total land-derived phosphate comes from detergents. The amount of nutrient exchange between sediments and the water column is dependent on the exposed surface area between the two media and not on the amount of nutrient material present. Low oxygen concentrations cause the release of phosphorus from the sediment. Several studies have found that under natural conditions an equilibrium is established between the phosphate concentration of the sediment and the water (Lee and Plumb, 1974). However, if these sediment nutrient reservoirs are covered by silt, or sand, no such interchange can take place. One study showed no phosphorus was released 0.54 cm below the surface of the bottom (Lee and Plumb, 1974).

Unlike many pollutants, phosphorus appears harmless by itself, but in combination with nitrogen,

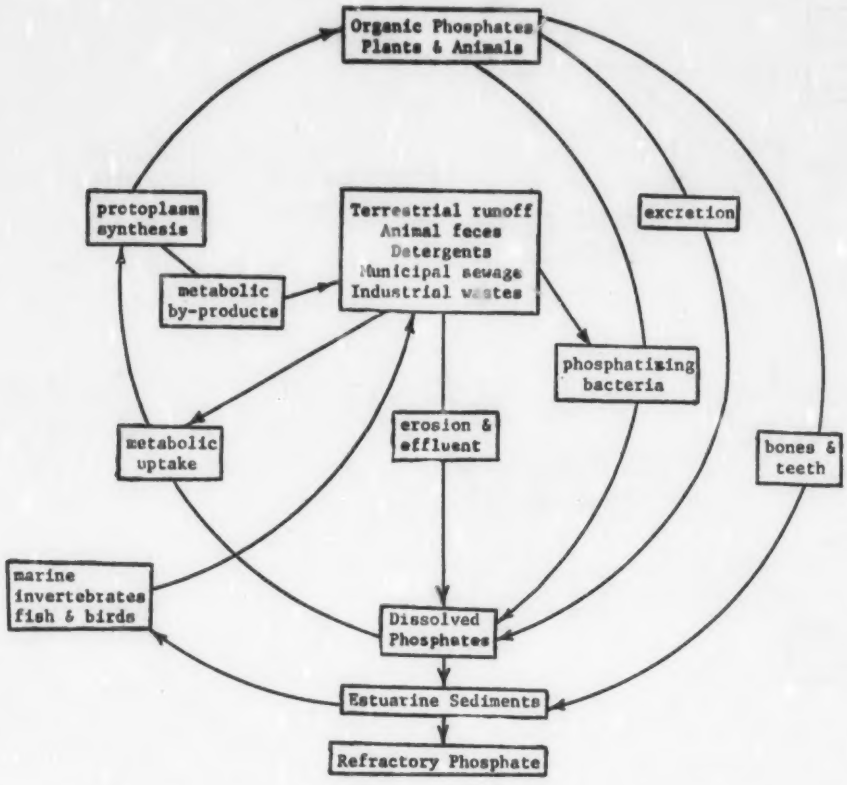


FIGURE 2.—The estuarine phosphorus cycle (modified from Odum, 1971).

it can change the whole biota (Redfield, et. al., 1963). Samples of water enriched with phosphate alone show no greater growth than control samples, while nitrogen-enriched cultures have shown tenfold growth in several cases (Ryther and Dunstan, 1971).

Carbon Compounds

The sources for most inorganic and organic carbon compounds in estuaries are terrestrial runoff, municipal and industrial discharges into rivers, and photosynthetic carbon fixation. A simplified carbon cycle for estuaries is given in Figure 3, which has been modified from Wangersky, 1972. Inorganic carbon is converted into organic carbon by photosynthesis. Organic carbon can be separated into particulate organic carbon (POC) and dissolved organic carbon (DOC) fractions by bacterial decomposition. Either of these can be associated with the sediments, the POC by settling, the DOC by adsorbing onto larger aggregations and settling to the bottom. Organic carbon is important as a nutrient because of the interconversion to inorganic carbon.

Since algal tissue contains between 35 and 50 percent organic carbon by weight, it merits classification as a major nutrient. In many cases, organic carbon may be directly correlated with nitrate distribution in a body of water. Carbon fixation rates are often stimulated by the addition of nitrogen or phosphate compounds as in the case of eutrophication. Organic carbon does represent an area of concern, but many authors believe that the reservoir of inorganic carbon compounds is in such excess that the rapidly cycling organic carbon is usually not a limiting factor under natural conditions.

Mineral and Trace Elements

In the late 1800's Dittmar studied 77 seawater samples and found chlorine, sodium, magnesium, boron, potassium, calcium, sulfur, sulfate, carbonate, bicarbonate and strontium represent from 99.7–99.9 percent of the total dissolved material. (Corcoran and Alexander, 1964.) The 0.2 percent remaining included the principal plant nutrients: nitrogen, phosphorus, and silicon, in addition to iron, copper,

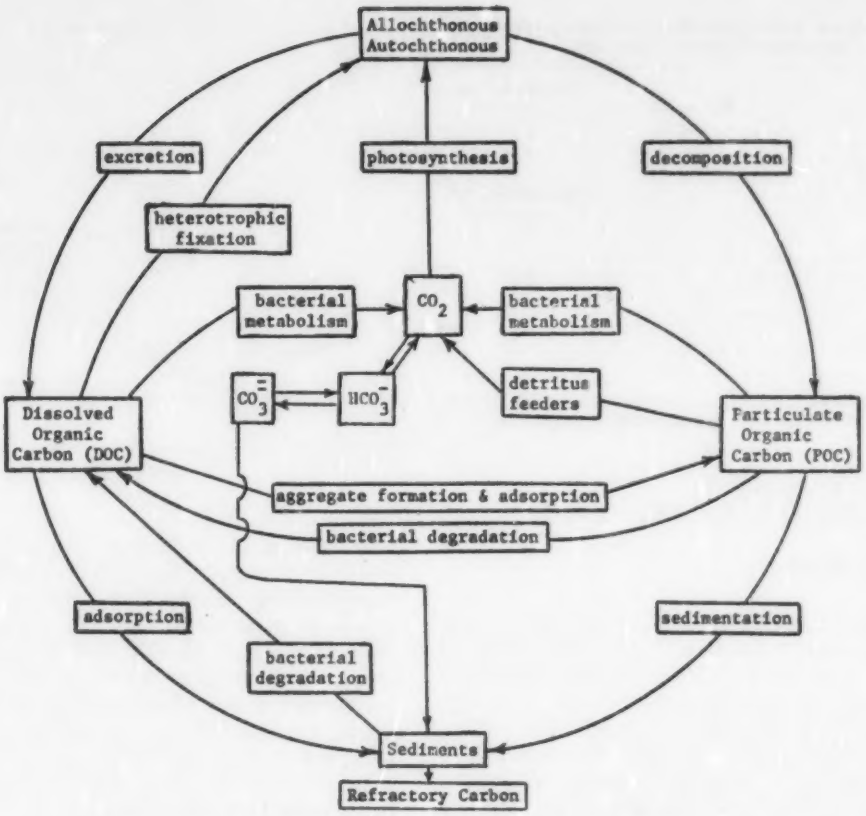


FIGURE 3.—The estuarine carbon cycle (modified from Wangersky, 1972).

obalt, and manganese. Iron, because of its role in emoglobin, catalases, and cytochromes is an es-ential element in life processes. Iron in the form f ferric hydroxide (rust) has been postulated by iolberg (1952 and 1954) to have a scavenger role n the accumulation of trace elements, allowing hytoplankton to concentrate them along with their ormal uptake of iron. Copper, another essential lement, is found in hemoglobin, cytochromes, and emocyanins, as well as being necessary in the tabilization of the chloroplast. It aids in oyster and arnacle attachment, formation of octopus melanin, nd the hardening of exoskeletons and egg encase-ents. However, its toxicity at high concentrations s evidenced by its use in antifouling paints.

The trace elements exist in all three phases: water, ediment, and the biota. Using zinc as an example, n the water column it can be in an ionic state or a omplexed form with many other molecules. While part of the estuarine sediment, it can be dissolved in interstitial water, ionically bound to charged clay and organic surfaces, entrapped within iron and manganese precipitates in addition to lattice and organic complexes. In the biotic phase, zinc is associated with an organism: bound to mucous membranes, enzymes, contained in cellular protoplasm or within the digestive system. This permits biological cycling as it passes up the food chain from the plankton through the carnivorous fish, and possibly returning to the sediments.

The concentrations of trace elements present in the estuary prevent them from being limiting factors for photosynthesis. Dittmar's hypothesis includes a general statement that the concentrations of these elements vary little in relation to each other in sea water. Trace elements can be toxic at concentrations above background levels (Doudoroff and Katz, 1961). EPA has set up a table listing "maximum acceptable concentrations" (Clark, 1974; EPA, 1973) for various substances; see Table 2.

Table 2.—Maximum acceptable concentrations for indicated substances. U.S. Environmental Protection Agency, 1973

Substance	Concentrations (mg/l)
Aluminum	1.5
Arsenic	0.05
Copper	0.05
Boron	N.A. adequate data not available
Fluorides	1.5
Iron	0.3
Lead	0.05
Manganese	0.1
Mercury	0.001
Nickel	0.1
Phosphorus	0.0001

The values represent the "maximum allowable concentrations" of toxic substances as established by EPA following a National Academy of Sciences Review in 1973.

NUTRIENT LOADING IN SIX MAJOR U.S. ESTUARIES

Cook Inlet, Alaska

Cook Inlet (see Figure 4) in the south central area of the state, exhibits a 30-foot tidal range, a rapid flow rate, and a large natural suspended sediment load. The estuary has an estimated 400–500 miles of tidal shoreline (1 percent of Alaska).

In Cook Inlet there are four major sources of nutrient loading: (1) municipal sewage discharges, (2) fish processing waste discharges, (3) salmon spawning wastes, and (4) turbid outwash—outflow from glaciers. Anchorage borders the inlet and discharges the sewage of nearly one-half of the state's population. The depth and flow rate of the estuary greatly reduces the impact of this nutrient load. However, with the discovery of oil, the Anchorage area will experience tremendous population growth. In 1963, oil was discovered at Middle Ground Shoal in Cook Inlet; in less than two years oil production exceeded 1,000 barrels per day per well ("National Estuary Study," 1970). Along the shores of Cook Inlet numerous fishing villages (Seldovia, Anchor Point and Homer) base their economies on chinook, pink and red salmon, king crabs and shrimp. It is a common practice for canneries to dispose of 20 percent by weight of salmon back into the inlet, producing unnaturally high nitrogen concentrations in small areas. Murphy et. al. (1972) concluded that there is some pollution near the Chester Creek and Cairn Point Outfalls, but as a whole, Cook Inlet is not polluted due to the high degree of turbulence, flow rate, and sediment transport. They further suggest that 200 million gallons per day of untreated domestic waste could be pumped into the inlet without causing an undesirable situation.

FIGURE 4.—Cook Inlet and Alaska (from "National Estuary Study," 1970).

In Alaska many fishing villages are located on small finger bays. The villagers utilize individual cesspools and septic tanks for sewage disposal, which seep nutrients into the coastal waterways (Department of Health and Welfare, 1967). In many small villages waste materials are stored frozen during the colder months and dumped onto intertidal beaches to be washed away. These practices of waste disposal permit contaminants to enter the ground waters, infecting wells and becoming a hazard to public health.

Brickell and Goering (1970), investigating the concentration of nitrogen in a pink salmon spawning stream (Sashin Creek, and its associated estuary, Little Port Walter on Baranot Island in southeastern Alaska), found that dissolved organic nitrogen ranged from 0.006 mg/L to 0.018 mg/L following spawning, indicating a tremendous nutrient loading from the decay of adult fish.

In the future, the anticipated population growth in Alaska will overload the current estuarine waste disposal methods and greatly impact these waters. Continued nutrient loading through human waste, commercial fisheries' waste, and industrial discharges will alter the natural equilibrium of these estuaries, especially during the warmer months.

Columbia River Estuary

The Columbia River Estuary has a high velocity flow rate. It is ranked seventh in total length (1,324 miles) and second in flow volume (behind the Mississippi) of any river in the United States. The yearly mean discharge has been calculated to be 170,000 cubic feet per second, with a watershed of

259,000 square miles. The elevation of the river drops from 2,650 feet to sea level, generating an enormous velocity and producing a large effluent plume into the Pacific (see Figure 5).

The Columbia River has significant impact on the adjacent Pacific coastal zone. During 1966 and 1967 the annual chemical input to the Pacific was estimated to be 10^8 moles of phosphate, 2.6×10^9 moles of nitrate, and 2.2×10^{11} moles of total carbon dioxide (Pruter and Alverson, 1972). Due to the high velocity and short retention time within the estuary, these levels of nutrients do not have enough time to produce adverse conditions. It has been reported that: "With the exception of slime growths (*Sphaerotilus natans*) in the lower river, the biological populations of the river are diverse and balanced, the opposite of eutrophic conditions. Although nitrate and phosphorus levels exceed desirable levels (particularly during high runoff periods), there are none of the usual symptoms of excess productivity such as noticeable variations in dissolved oxygen saturation. There are no trends to suggest increasing eutrophication" (EPA; National Water Quality Inventory, 1974). The slime growths mentioned were found to be associated with pulp and paper mill wastes and became a problem to the fishermen by fouling their nets and also to those using the river for recreation. By the summer of 1972, practically all of the slime growth had been eliminated following a program of more extensive effluent treatment by the paper plants. The recommendation made was that all pulp and paper mills should at least have mechanically cleaned primary waste treatment facilities to reduce the release of paper fibers into the river.

FIGURE 5.—The Columbia River showing summer effluent plume and dam locations (modified from EPA, National Water Quality Inventory, 1974).

Table 3.—Columbia River: Distribution of point waste discharges by source (1972-73)

Waste source	Flow *m.g./d.	BOD lb./day	Phosphorus lb./day	Nitrates lb./day
Municipalities	113.6	145,132	5,800	16,372
(Portland)	(71.5)	(86,962)	(3,102)	(9,340)
Pulp and paper	395.1	606,211	993	706
Chemicals	85.3	7,418	107	483
Aluminum reduction	91.3	4,300	493	415
Washington public power	1,710.0	—	—	—
AEC Hanford Works	239.5	—	1	—
Food processing	47.2	4,033	39	8
Other	36.0	1,634	75	95
Total	2,768.0	768,728	7,508	18,059

* Million gallons per day.
Modified from National Water Quality Inventory; 1974.

Nutrient enrichment can be divided into controllable point discharges and generally uncontrolable non-point discharges coming from the normal land runoff. The point discharges come from a variety of sources on the river including municipal dumping, pulp and paper mills, food processing plants, grain washing plants, and so forth. Each of these makes contributions to the Columbia through industrial discharges. A point waste discharge for the Columbia River is given in Table 3. These point discharges are generally minor in their influence on the water but twice they have been involved in pollution problems in the lower river. Fortunately, the volume and velocity of the Columbia River have been great enough to maintain a quality that rarely drops below the very high standards set by the States of Oregon and Washington. While the quality of water in the Columbia remains generally high, some of her tributaries experience nutrient levels higher than state standards.

Sufficient amounts of all nutrients are present to support a diverse and abundant biota. During most of the year, nitrates are present in concentrations far greater than the 0.3 mg/L limit set for the usual formation of algae blooms (EPA; National Water Quality Inventory, 1974). In fall and winter nitrate median concentrations range from 0.3 to greater than 0.4 mg/L from McNary Dam (RM330) to the mouth; in spring, the median exceed 0.3 mg/L from Longview (RM68) to the mouth. Concentrations at McNary Dam exceed 0.8 mg/L in 15 percent of the readings; however, the effect is very slight. During the summer months when conditions are optimum for algal growth, nitrate concentrations fall well below the 0.3 mg/L value.

Phosphorus concentrations show a similar annual trend. From McNary Dam to the mouth, during

the fall and winter, the median phosphorus value exceeds the 0.05 mg/L value set as the limit. During the warmer summer months, the median value is consistently below the limit value except in the lower 60 miles. It appears that total phosphorus concentrations can be correlated to river flow. Low flow years experience lower values (1967–1969), while higher flows (1970–1972) produce higher median concentrations. Fortunately, the Columbia River's nutrient levels are sufficient, with the vast majority of nitrates and phosphates coming from natural non-point sources. Phosphorus comes from soil-bound materials and is runoff dependent. "In 1972, 6 percent of the annual loading of the Columbia occurred from point sources discharging directly into the Columbia, 65 percent was carried to the Columbia by its major tributaries, and 29 percent was accounted for by other mechanisms—among them minor tributaries, direct runoff, and sedimentation" (EPA, National Water Quality Inventory, 1974).

Therefore, the Columbia River receives vast amounts of nitrogen and phosphorus principally from land runoff, but natural conditions have not permitted eutrophic conditions to occur. Point sources contribute large amounts of nutrients but the rate and volume of river flow is enough to disperse these substances during the algal growth season. It appears that some of the tributaries are experiencing increased eutrophication. The Columbia River has been sampled for 82 years and now has 89 monitoring stations along its length, which should enable recognition of potential problems.

San Francisco Bay

San Francisco Bay represents the oceanic outlet for the Sacramento River, San Joaquin River, and many lesser rivers that drain the Central Valley of California into the Delta (see Figure 6). Its history is unusual; in about 1850 the bay complex was estimated to be 700 square miles but by 1960 extensive diking and filling had reduced the area by 38 percent to 435 square miles. In addition, the bay area boasts a population in excess of five million, which discharges industrial and municipal wastes into the rivers and bay. This population represents a fourfold increase over census figures of 1930.

In 1969, municipal and industrial wastewater discharges were estimated at approximately 600 million gallons per day and this figure is forecast to increase to over 2,100 million gallons per day by the year 2020 (Kaiser Engineers, 1969). These figures do not include industrial use of water for cooling purposes. Natural runoff has increased due to increased urban development.

FIGURE 6.—San Francisco Bay (from Kaiser Engineers, Final Report to State of California, 1969).

In San Francisco Bay, nutrient overenrichment is the major problem. The rivers entering the bay are rich in nitrogen, phosphorus and carbon from point sources (municipal and industrial) and non-point sources (natural and agricultural) from the California Central Valley. Low velocity riverflows produce a residence time for the northern reach of San Francisco Bay estimated at 100 days according to the California State Water Resources Control Board in 1971. This time period permits extensive nutrient cycling and high rates of carbon assimilation. "Recent studies have indicated that nitrogen and phosphorus concentrations were from 10 to 100 times greater in the Delta than those reported for substantial growths of algae" (Kaiser Engineers, 1969). Reported concentrations of total nitrogen ranged from 0.2 to 2.5 mg/L with the higher values found at the San Joaquin River near Stockton, an agricultural area. An unusual feature of the bay is that nitrogen and phosphorus are at too high levels for them to be limiting eutrophic conditions. A California State Water Resources Control Board Report (Kaiser Engineers, 1969) states that in the Suisun Bay (see Figure 6) during periods of maximum phytoplankton concentration, no more than 17 percent of available nitrogen was being utilized.

The report further states that the possibility that phosphorus could be the limiting nutrient is even less credible. Data from 1961–1964 computes that municipal and industrial sources contribute 53 tons per day of total nitrogen and 42 tons per day of total phosphates (Pearson, Storrs and Selleck, 1969).

Phytoplankton blooms occur frequently. In general, algal populations found in the bay are 1/10 to 1/100 of those found in the delta region; however, densities of greater than 4 million cells per liter have been observed below Dumbarton Bridge. Blooms occur almost every summer. Typical summer plankton counts in the delta area range from 3 million cells per liter in the Sacramento River to greater than 30 million cells per liter in the San Joaquin River which normally exhibits much higher values than the other inflowing rivers (Kaiser Engineers, 1969). Therefore, nutrient enrichment and eutrophication are a major water quality problem for the bay-delta system. The increasing volume of wastes expected in the future, coupled with the reduced freshwater flow caused by the development of the Central Valley Project and the State Water project influenced Kaiser Engineers (1969) to project: "Within the preceeding context, it is believed that the bay-delta system has no assimilative capacity for wastes above the quantities now being discharged. Eutrophication of the system, particularly in the delta and south bay, is well advanced. Increasing waste loads and the decreasing availability of flushing water from the Sacramento and San Joaquin Rivers will inevitably accelerate the eutrophication of the system."

In the Final Report for the California State Water Resources Control Board, comparison was made between San Francisco Bay and Lake Erie. The Report states many differences between the two bodies of water: size, salinity, Erie's 920 day residence time vs. the bay's 100 day period, et cetera . . . but the mean soluble phosphate content is 10 times that of Lake Erie's and the bay's average nitrate concentration is usually three times higher than Erie. Furthermore, the median coliform bacteria content of San Francisco Bay, which is an indicator of the presence of domestic wastes, is from 5 to 250 times that which is reported for Lake Erie.

Galveston Bay, Texas

The Galveston Bay Estuary is made up of about 1,022,000 acres including 383,400 acres of water, 230,000 acres of rice farms and cattle ranges, and 190,000 acres of urban and industrial areas; see Figure 7 ("National Estuary Study," 1970).

The estuary exchanges water with the Gulf of

FIGURE 7.—Galveston Bay, Tex. (from EPA Proceedings in the Matter of Pollution of the Navigable Waters of Galveston Bay and its Tributaries, 1971).

Mexico in three places: Bolivar Pass, San Luis Pass and Rollover Pass. In 1914 the Houston ship channel was constructed, making Houston a major seaport with entry from the Gulf of Mexico. The major direct effect has been oil pollution from ship traffic and from the development of petrochemical industries along the Houston ship channel. The indirect effect has been the tremendous urban development and other industrial growth in the entire area. These have produced major chemical and biological changes in Galveston Bay.

Under the Texas Water Quality Act of 1967, permits are issued to municipalities and industries regulating disposal into Texas estuaries. By 1971, the Environmental Protection Agency had granted 141 municipal and domestic sewage permits and 136 industrial permits. The total permitted discharge of waste effluent to Galveston Bay and tributaries was 779 million gallons per day: 583,000 pounds suspended solids; 270,000 pounds BOD, and 1,657,000 pounds COD. The 136 industrial waste discharges were allowed to add 563 million gallons per day in total effluent, most of which enters into the Houston ship channel. The remaining 215 million gallons represented effluent from the 141 municipal and domestic waste sources. These sources contribute high levels of coliform bacteria which have closed many of the shellfish areas within Galveston Bay. Of the 277 permits mentioned above, the waste treatment needs and status of 189 of them were not listed, and an additional 40 provided either in-

adequate or no treatment at all. Only 22 were listed as being in compliance with permit requirements (EPA Galveston Bay Conference, 1971).

Major nutrient alterations have occurred frequently in the recent history of Galveston Bay. Wallisville Dam, located on the Trinity River four miles above its entrance into the bay, will eliminate "20,000 acres of brackish ponds, sloughs, marshes, and bottomland, nearly all of which biologists of the U.S. Fish and Wildlife service regard as prime shrimp and finfish nursery grounds with an annual productive capacity of not less than $300 an acre and probably more" (Carter, 1970). This marshland loss will substantially alter the nutrient input of Trinity Bay which is part of the Galveston Bay complex. The nutrients contributed by the Trinity River support the tidal marshes, the estuary and Galveston Bay. The 0.5 feet tidal fluctuation contributes additional nutrients from the tidal marshes to the estuary. McCullough and Champ (1973) reported that 255 miles or half of the entire length of the Trinity River was impacted by municipal and industrial waste discharges from the Fort Worth-Dallas area before organic carbon concentrations returned to background levels. Also, the authors calculated that the Trinity River exports an estimated 3.52×10^4 metric tons/year of total organic carbon into Trinity Bay, utilizing data from the 1972-1973 study period.

Several other human activities have a potential for increasing the impact of nutrient loading in Galveston Bay:

1. Silting in at the new bridge at San Luis Pass, a process that is increasing the water mass retention time.
2. Increased dredging activities that include $2,807,000 in 1970 in the polluted Houston ship channel, which was necessary for navigation.
3. Escalation in recreational construction of bay homes and bay front properties by diking marshes and dredging activities. "In sum, Galveston Bay is providing a classic case history of an estuary that can be rescued from its troubles only by determined and imaginative effort—the solutions to the bay's problems seem to lie in large scale research, ambitious programs of pollution control plus tough enforcement and a close watch on the outfalls" (Carter, 1970).

Pamlico Sound

The Pamlico Sound and adjacent Albermarle and Currituck Sounds represent a drowned North Carolina coastal plain separated from the Atlantic Ocean by the Outer Banks (see Figure 8).

FIGURE 8.—Pamlico Sound (from "National Estuary Study," 1970.)

This entire complex makes up the second largest estuarine area in the eastern United States with Chesapeake Bay being first (Schoenbaum, 1972).

Currituck Sound	102,400 acres
Albemarle Sound	302,000 acres
Pamlico Sound	1,088,000 acres
TOTAL	1,492,000 acres
Chesapeake Bay	2,816,000 acres

Exceeded only by Alaska and Louisiana, North Carolina contains an estimated 2,200,000 acres of estuarine area (Rice, 1968). Shallow water characterizes these estuaries with a maximum depth of 7 feet in Currituck Sound and 20 feet in Pamlico Sound, but lessens to a few inches in many of the numerous shoal areas. In Washington, N.C., the Tar River becomes the Pamlico River flowing east to the Pamlico Sound (see Figure 8). An important feature is the slow riverflow allowing longer residence time and consequently a much slower flushing rate. Lunar tides are negligible due to the Outer Banks, and the extreme shallowness allows wind mixing of the water producing turbid conditions during most times. (Copeland and Hobbie, 1972).

Copeland and Hobbie (1972) have reported that

nitrogen appears to be the nutrient limiting eutrophication in the Pamlico River Estuary. The soils of this region are unusually high in natural phosphorus, allowing large amounts to leach into the waterways. Natural deposits are high enough to make mining (for use in fertilizers) profitable by the Texas Gulf Sulphur Company (TGSCo) which contributes quantities into the Tar River. This additional phosphorus enters the water column and becomes part of the sediment, particularly near the TGSCo effluent pipes. Under conditions of low oxygen, significant amounts of this phosphorus are released from the sediment to the overlying water mass. Copeland and Hobbie (1972) have reported that:

> When the total unfiltered phosphorus data were summarized for the upper, middle and lower river, it became obvious that there had been a general increase in the concentration of phosphorus in the upper river over three years of sampling (67–69). In spite of the scatter of values and seasonal changes, there was a tripling in the phosphorus concentration in the upper river . . . the middle river was greatly affected by the concentration of phosphorus entering from Texas Gulf Sulfur . . . the lower section . . . also seems to be strongly affected by Texas Gulf Sulfur's activities . . . while it is difficult to say whether or not the amount of phosphorus reaching Pamlico Sound is increasing, most of the time only low levels reach the Sound.

Yentsch (unpublished data; NAS, 1969) has postulated 2.8 μg of phosphate per liter as the approximate upper limit for unpolluted coastal waters. This value is exceeded most of the time in the Pamlico area but eutrophic conditions do not exist because "it appears that nitrogen is limiting in this estuary and that the polluting effects of the Texas Gulf Sulphur phosphate are slight at this time." (Copeland and Hobbie, 1972). Other required micronutrients appear to be abundant. Experiments were conducted adding phosphorus to the water but increased photosynthesis did not occur. Added nitrogen produced significant increases in carbon assimilation.

In summary, phosphorus by itself is relatively harmless in the Pamlico Estuary area but if nitrogenous compounds become available to the system, excessive eutrophication could occur.

Chesapeake Bay

The Chesapeake Bay represents the largest estuarine area in the eastern United States (2,816,000 acres), having major freshwater flow from the Susquehanna River, Potomac River, Rappahannock River, and the James River along her western shore ("National Estuary Study," 1970); see Figure 9.

The Potomac River itself drains 14,670 square

FIGURE 9.—Chesapeake Bay (from "National Estuary Study," 1970).

miles and extends 100 miles southeast from Washington, D.C., to the bay (Jaworski et al., 1971). Major cities contributing to the bay or her tributaries include Baltimore, Md., (pop. 905,759), Washington, D.C., (756,510), Richmond, Va., (249,430) and Norfolk, Va., (307,951). These urban areas contribute to the nutrient load through municipal and industrial wastes, land silt runoff, and wastes contributed by the estimated 110 million tons of cargo annually shipped through the bay ("National Estuary Study," 1970). The Susquehanna River contributes 600,000 tons of terrigeneous silt to the Chesapeake each year, but this volume seems insignificant to the estimated 2.5 million tons originating in the smaller Potomac Basin. Nearly half of the economically important oyster beds located in the upper bay have been destroyed or moved lower in the bay due to this massive sedimentation. Cities and suburban areas are presently adding uncontrolled quantities of silt into Chesapeake Bay ("National Estuary Study," 1970).

Regarding nutrient enrichment in Chesapeake Bay, there are two considerations: (1) the predominant influence of three principal watersheds on the nutrient balance of the bay—the Susquehanna, the Potomac, and the James; and (2) the seasonal

nature of nutrient enrichment, whereby the majority of nutrients transported are via nontidal discharges (Guide and Villa, 1972). There is a relationship between river discharge and nutrient loadings, especially NO_2 and NO_3 as nitrogen. High NO_2 and NO_3 as nitrogen loadings are indicative of land runoff as contrasted to TKN as nitrogen loadings which are attributable mainly to treatment plant discharges. Conversely, total phosphorus as PO_4 is more difficult to characterize since it tends to absorb to particles and sediments. During low flow phosphorus is retained in bottom deposits in the stream channel and is unavailable due to sedimentation. The greatest impact of these nutrient loadings occurs during periods of low flow (and high temperature) during which high retention times result in algal blooms. Guide and Villa (1972) have by regression extrapolation over a 15-month study period (Nov. 1969-May 1970) calculated the primary source of nutrients entering Chesapeake Bay as follows:

	Loadings (Lbs/Day) as %					
Tributary Watershed	T PO_4 as PO_4	Pi	TKN as N	NO_2 + NO_3 as N	NH_3 as N	TOC
Susquehanna River	49	54	60	66	71	51
Potomac River	33	27	23	25	15	27
James River	12	13	10	6	11	12
Rappahannock River	2	2	3	1	1	3
Pamunkey River	2	2	2	1	1	4
Mattaponi River	1	1	1	<1	<1	2
Chickahominy River	1	1	1	<1	<1	1

Clark, Guide, and Pheiffer (1974) have developed the following conclusions regarding the nutrient loading in the Susquehanna River:

1. Runoff from agricultural land (42 percent of the study area) accounted for 75–85 percent of the non-point source phosphorus contribution, 60–70 percent of the TKN contribution, and more than 90 percent of the nitrate nitrogen contribution from all nonpoint sources.
2. Runoff from forested land (53 percent of the study area) accounted for 10–15 percent of the non-point source phosphorus load, 25–30 percent of the TKN load, and about 5 percent of the nitrate nitrogen load from all non-point sources.
3. Phosphorus is considerably more manageable than nitrogen in the lower Susquehanna River Basin during all flow conditions.
4. In order to protect the biological integrity of the upper Chesapeake Bay, a sizeable reduction (70–90 percent) in the existing point source contribution of phosphorus must be realized.
5. The effectiveness of nitrogen control at point sources is questionable unless attention is given towards reducing the existing load from agricultural runoff.

Guide and Villa (1972) have also reported the existence of a direct relationship between total and inorganic phosphorus concentrations as PO_4 and river discharge. They found that higher than normal flow resulted in total and inorganic phosphorus surges from the upper Susquehanna River Basin.

Jaworski et al., (1971) report that 325 million gallons per day of wastewater is discharged from municipal treatment facilities which serve the Washington area. Schubel (1972) adds that this present sewage discharge contains more than six metric tons of phosphorus and 10 metric tons of nitrogen per day with these values expected to double in the next 30 years. During periods of low river flow (75 m^3/sec.) these inputs drastically alter the nutrient load of the Potomac, increasing the concentration of phosphorus by about 180 μg/liter (Carpenter, et. al., 1969). Total nitrogen in the river varies seasonally but generally appears highest from January to March. Total phosphorus reaches its highest values during the late fall and early winter. Agricultural drainage and sewage in the Potomac produce adverse phosphate conditions above Washington, D.C. Measurements made in 1965–1966 showed that nitrate concentrations in the river above Washington were 100–150 μg at./liter during periods of high river flow, and phosphate concentrations were 5 μg at./liter (Carpenter, et. al., 1969). This loading in summer and fall produces large algal populations of blue-green algae *Microcystis aeruginosa* which are present from the metropolitan area as far downstream as Maryland Point (40 river miles). Comparison of chlorophyll *a* concentrations for 1965–1966 to 1969–1970 for Smith's Point (River Mile 0) and Indian Head (River Mile 75 from the mouth of Chesapeake Bay) indicate that algal populations have not only increased in density in later years but have become more persistent over the annual cycle (Jaworski, et. al., 1971).

Organic carbon studies in the Patuxent River, Md., have found that the concentrations of dissolved organic carbon (DOC) were higher than particulate organic carbon (POC). The DOC to POC ratio was 1.7:1 for the 48 river miles studied (Hill, 1973). An analysis of variance indicated that DOC varied significantly with salinity while POC varied significantly only at low and high salinities. Both DOC and POC concentrations decreased down river (Hill and Champ in manuscript).

Thus far, Chesapeake Bay itself has been able to avoid the problems associated with nutrient loading leading to eutrophic conditions which are present in many tributaries (i.e. Potomac River, Patuxent River and Black River). In the main

body of the upper bay nutrient levels and phytoplankton production are high, but the grazing rate is also high, thereby preventing an undesirable buildup of algae. Nutrient levels are probably near the upper limit for healthy conditions in the bay. The discharge of improperly treated sewage and municipal wastes constitutes the most serious immediate threat to the Chesapeake Bay estuarine system (Schubel, 1972).

CRITICAL PROBLEMS AND RECOMMENDATIONS

Current U.S. Trends in Nutrient Loading

The current trend in expansion, development and population growth of coastal cities will greatly accelerate man's impact on the Nation's estuaries. Nutrient loading is increasing in general with some harmful results. The 1974 National Water Quality Inventory stated that the "chemical and physical measurements taken in 22 waterways show that the pollutants receiving the most widespread controls (including bacteria and oxygen demand) greatly improved in the last five years." It continued to report that "nitrogen and phosphorus, the nutrients most frequently associated with eutrophication, showed worsening trends." The overall effect of these opposite trends is not completely understood; however, if the present increased use of chlorine as a disinfectant is considered, lower bacteria counts and BOD levels could be explained even though nutrient loading has increased. Phosphorus levels were high enough to exceed suggested levels in up to 57 percent of the reaches studied. In addition, "82 percent of the reaches showed increased levels of phosphorus from 1968–1972 over the previous five years ... with nitrogen exceeding reference levels in one quarter of the reaches measured, and increased in up to 76 percent of the reaches." Table 4 presents the percent of the reaches exceeding reference levels and the percent change from 1963 to 1972.

The National Water Quality Inventory (1974) represents a landmark work in the study of the United States continental waterways because it was a cooperative effort by the states in association with the Environmental Protection Agency. The report studied the 10 longest rivers in the country; the 10 rivers with the highest streamflow volume; and the rivers or harbors where the 10 largest urban areas are located.

In 1972, the National Pollution Discharge Elimination System (NPDES) Act was passed requiring permits for discharging from a point source into the nation's waters. These permits specify the amounts of pollutants that each discharge point is allowed. By March 1974, about 41,000 permit applications had already come in with an expected 34,000 still to be filed.

Table 4.—Major waterways: Reference level violations, 1963–72

Parameter	Reference level and source	Percent of reaches exceeding reference levels		
		1963–72	68–72	Change
Suspended solids	80 mg/l aquatic life	26	14	−12
Turbidity	50 JU aquatic life	28	28	0
Ammonia	0.89 mg/l aquatic life	16	6	−10
Nitrate (as N)	0.9 mg/l nutrient	12	24	+12
Nitrite plus nitrate	0.9 mg/l nutrient	18	26	+8
Total Phosphorus	0.1 mg/l nutrient	34	57	+23
Total Phosphate	0.3 mg/l nutrient	30	41	+11
Dissolved Phosphate	0.3 mg/l nutrient	11	22	+11
Chlorides	250 mg/l water supply	12	9	−3
Sulfates	250 mg/l water supply	12	12	0

Modified from National Water Quality Inventory; 1974.

Municipal sewage contributes large amounts of nutrients to the river or estuary depending upon the treatment it receives. Primary treatment removes the particulate matter from the raw sewage thereby removing 20–35 percent of the biological oxygen demand (BOD). Tertiary waste treatment, using the effluent from the secondary process, involves nutrient removal (nitrogen and phosphorus) and can reduce BOD effluent concentrations significantly below secondary treatment. Table 5 lists the number of municipal discharges by treatment level and by state.

Agricultural sources are more difficult to study. Most farms are not considered to be point sources and are not required to have permits, but large feedlots, fish hatcheries, and return flows from irrigated fields must have permits. Most operations of this type are found in the west and midwest with about 6,500 permit applications expected under the National Pollution Discharge Elimination System (NPDES).

Increased nutrient loading represents a potential hazard to the nation's estuaries which may have a profound effect on a type of American way of life. Many communities bordering the estuaries depend upon the estuarine ecosystem for their economic and cultural livelihood. In tidewater Virginia, for example, fishing and oystering have been community pursuits for well over a century and they could easily be eliminated, impacting economic and social structures. Socially, the estuaries annually provide recreation for millions in the form of swimming, boating and fishing. In North Carolina, the annual

Table 5.—Municipal discharges by state (From EPA National Water Quality Inventory, 1974)

State	Number of municipal facilities by treatment level							Number of facilities by population served			
	Total	Primary	Adequate secondary	Inadequate secondary	Unclassified secondary*	Tertiary	None	Less than 1,000	1,000 to 9,999	10,000 to 100,000	Greater than 100,000
Alabama	261	32	65	42	101	0	21	96	137	27	1
Alaska	38	8	6	1	25	0	4	31	4	2	1
Arizona	119	3	7	13	75	1	20	51	54	11	3
Arkansas	211	18	5	29	157	0	2	71	118	21	1
California	659	119	69	62	375	11	23	196	300	140	23
Colorado	233	11	15	16	168	7	16	119	86	24	4
Connecticut	180	39	11	7	84	6	33	88	44	45	3
Delaware	25	5	8	8	2	0	2	8	15	1	1
District of Columbia	1	0	0	1	0	0	0	0	0	0	1
Florida	582	40	173	147	189	14	19	261	240	78	3
Georgia	474	64	207	114	62	2	25	264	173	33	4
Hawaii	39	5	9	3	15	0	7	11	22	6	0
Idaho	129	17	16	42	37	0	17	67	53	9	0
Illinois	828	71	183	230	287	31	26	313	416	92	7
Indiana	741	43	37	80	355	104	122	450	241	44	6
Iowa	639	27	23	122	350	0	117	421	195	22	1
Kansas	632	98	13	67	442	0	12	405	192	33	2
Kentucky	284	25	6	5	238	3	7	96	166	20	2
Louisiana	188	11	1	2	159	0	15	42	111	33	2
Maine	68	15	4	3	24	0	22	27	34	7	0
Maryland	304	28	61	57	141	0	17	195	88	19	2
Massachusetts	153	37	0	0	77	0	39	56	56	33	8
Michigan	482	108	59	58	132	13	112	184	245	48	5
Minnesota	520	53	15	92	311	15	34	295	195	27	3
Mississippi	312	7	4	11	277	0	13	170	114	27	1
Missouri	454	20	18	31	376	0	9	213	205	30	6
Montana	163	24	2	2	127	2	6	109	46	8	0
Nebraska	496	41	4	24	385	7	35	374	109	10	3
Nevada	39	3	7	2	24	1	2	14	21	1	3
New Hampshire	45	18	0	2	23	0	2	10	26	9	0
New Jersey	339	84	35	33	193	4	5	73	176	80	10
New Mexico	82	1	8	27	45	0	1	27	39	14	2
New York	747	472	34	66	135	16	24	312	329	86	20
North Carolina	1,156	114	150	166	634	33	59	901	200	53	2
North Dakota	256	15	3	11	216	0	11	194	54	8	0
Ohio	1,033	89	219	123	298	132	172	576	344	101	12
Oklahoma	385	12	76	157	137	0	3	199	155	28	3
Oregon	249	42	39	54	91	2	21	117	102	28	2
Pennsylvania	1,877	164	429	263	494	253	274	1,225	518	121	13
Rhode Island	27	8	1	7	2	2	7	11	6	8	2
South Carolina	1,416	113	37	93	1,067	82	24	1,202	188	25	1
South Dakota	227	19	93	74	28	2	13	169	50	8	0
Tennessee	265	17	60	42	134	6	6	102	133	26	4
Texas	911	73	172	490	171	1	4	239	530	123	19
Utah	89	14	23	21	17	1	13	42	29	16	2
Vermont	79	34	1	4	31	0	9	34	41	4	0
Virginia	956	99	54	90	673	22	18	733	184	31	8
Washington	363	95	22	39	182	2	23	202	120	37	4
West Virginia	578	149	6	10	385	5	23	472	94	12	0
Wisconsin	562	84	101	195	132	14	36	326	197	36	3
Wyoming	85	9	0	2	70	1	3	52	29	4	0
Guam	1	0	0	0	1	0	0	1	0	0	0
Puerto Rico	82	25	5	47	1	0	4	6	66	9	1
Virgin Islands	1	1	0	0	0	0	0	0	1	0	0
Total	21,065	2,723	2,575	3,287	10,153	795	1,532	11,852	7,291	1,718	204

* Data insufficient to classify further.

marine sport fishing value was estimated at 9 million dollars in 1960, with marine commercial fisheries valued at 3.6 million dollars. Estuarine dependent oceanic fish were valued at 2.5 million with waterfowl hunting valued at 0.2 million dollars. Therefore, the annual primary economic value of fish and wildlife resources of the North Carolina estuarine areas were in excess of $15 million in 1960 (National Estuarine Study, 1970). In 1966 in Chesapeake Bay $30 million dollars worth of fish and shellfish were harvested, half of this oysters. The 20 million pounds of oyster meat harvested in 1966 dosen't compare well with the 177 million pounds harvested in 1880 Oyster harvesting could evidently be prohibitec

in some areas if pollution and eutrophication are allowed to continue. Swimming has been banned in some rivers, for instance in the Potomac River, where up to 5 million gallons of untreated raw sewage per day are currently being discharged due to treatment plant overloads.

Nutrient loading in some estuaries has accelerated eutrophication, altering the biota and reducing species diversity. The species considered to have economic value generally do not thrive in eutrophic conditions. Perhaps the most significant alterations in the biology of eutrophic estuaries would be the reduction in embryonic and juvenile survival rates and the reduction of alternative food webs. Oysters, clams, lobsters, crabs, and many species of fish have been placed in stressing environments. The resulting biota is composed of large populations of polycheate worms, trash fish, and echinoderms. In tropical waters, sewage dumping accelerates algae production which drastically alters the production of coral reefs. On the west coast, sewage disposal stimulates large populations of sea urchins, which over-graze the giant kelp beds, eliminating nursery areas for larval and juvenile forms, habitats for fish, sea otters, and numerous invertebrates. These alterations are at the interacting ecosystem level and cause irreversible damage.

With world food production today at a premium, the 4.06 billion pounds of U.S. estuarine commercial fish and shellfish (1967) are a very important source of protein. Several investigators have reviewed the potential for controlled cultural eutrophication as a new source for man's food (Sawyer, 1970). The philosophy is that added nutrients increase phytoplankton biomass, which could be channeled into food chains specifically for the production of commercially important fish or shellfish (aquaculture). This could serve a twofold purpose: first, it could use treated sewage as a nutrient source, and secondly, it could produce a vast industry if developed. The statistics compiled for 1969 by the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration indicate that the Gulf of Mexico Fisheries contributed $152 million, or about 30 percent of the total U.S. fisheries production ($518.5 million). In 1970 the gulf shrimp fisheries alone were estimated to be worth $108 million.

A smooth system doesn't exist whereby federal agencies administer to state agencies, which control local operations, with one federal group as the lead organization responsible for coordination of estuarine programs. Instead, a free lance theory of operation exists which can break down interagency cooperation. Federal "maximum acceptable permissible concentrations" exist in many cases but these need to be evaluated as standards for water quality and as methodology incorporating both accuracy and simplicity. EPA and other governmental groups are on the right track in coordinating activities and defining critical values, national zones and areas of study. However, a total cooperative program will be required to reverse the national trend. An integrated systems approach will enable a better qualification and quantification of estuarine dynamics, eliminating problems associated with interpreting individual parameters. For enforcement policy to be effective, it must be uniform, and those at fault must be given an economic incentive for corrective action. If fines are not enough, stiffer measures must be taken to develop cooperation.

A nationwide monitoring system using standardized methodology is needed which could be state and federally supported and staffed. This allows for progressive trends to be realized and would be beneficial in discovering problem areas. Phosphates, largely coming from households, represent an easy source for action but certainly that is not enough. Nitrogenous compounds, generally considered to be the limiting nutrient in coastal areas, need to be strictly monitored. New technology in municipal sewage treatment has increased the efficiency of phosphate removal; however, there must be a greater effort to investigate the impact of specific nutrients on specific estuaries. Fertilizers could be made less deleterious simply by increasing the efficiency of their uptake.

Nutrient loading in the nation's estuaries exists as a problem between good management (cooperative policy and decision) and enforcement of regulations.

RECOMMENDATIONS

1. *Formation of a National Estuarine Coordinating Board.* The Board would consist of representatives from the various state and federal agencies. The Board would be responsible for approving management programs and directing the enforcement of policies and enactments. The Board would be responsible for reviewing every estuarine proposed project prior to submission to Congress for funding, similar to the Board of Engineers for River and Harbors for civil works projects. The Board would be responsible for coordinating estuarine monitoring surveys and evaluating national trends. The Board could be housed in the Office of Coastal Zone Management of NOAA.

2. *Development of a national policy* on coastal land use with regard to construction of recreational homes

and beach houses, et cetera, modeled after the Currituck County Plan in North Carolina. This plan concentrates housing and populations in small areas which enables better sewage treatment and reduces the human impact on the system.

3. *Formation of a Nationwide Estuarine Monitoring System* in which the many regional programs would be coordinated and manned by federal and state authorities using standardized techniques. The data could be stored in EPA STORET System with a system of quality control instigated.

4. *Designation of natural* undisturbed estuarine areas as biospheres to be preserved and protected for research and long term studies.

5. *Seasonal and long term studies* evaluating the impact of the addition of specific nutrients to specific estuarine ecosystems to determine the limiting nutrient.

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ACKNOWLEDGEMENTS

Sincere appreciation is extended to William J. Rue, Jr., without whose valuable assistance this manuscript could not have been compiled. A. R. Armstrong, Roland F. Smith, and Paul R. Becker are to be thanked for their critical review. Rosie Valigra's efforts in editing and typing the final manuscript are also greatly appreciated.

EFFECTS AND CONTROL OF NUTRIENTS IN ESTUARINE ECOSYSTEMS

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ABSTRACT

Almost all nutrients entering estuaries come via streams, with smaller amounts from precipitation and the ocean. Oversupplies of nutrients are transported to estuaries from land-use activities, sewage disposal, industry, agricultural wastes, urban runoff and mining. Increased nutrients cause algal blooms, which lead to more subtle estuarine ecological problems.

Many processes affect nutrient concentrations during transportation and after they reach the estuary. Absorption, dilution, coagulation, and sedimentation decrease nutrient concentrations in estuarine waters. Since an equilibrium is established between water and sediment, nutrients are also released to the water from sediment storages. Biological activities influence nutrient cycling and concentration.

Several control mechanisms are discussed. The potentially most successful and least harmful means of controlling nutrient inputs to estuaries is to control them at their source. After nutrients reach estuaries, there is little possibility for effective reduction in nutrient concentrations.

Suggestions for research to develop new and more effective means to control nutrient inputs to estuaries are made. These include denitrification, land-use practices, natural filters, treatment innovations, and new ways to assess ecosystem response. Finally, management mechanisms are suggested to influence nutrient inputs and to minimize effects.

INTRODUCTION

The Problem

In all aquatic systems, nutrients are important raw materials supporting a basic biological activity, primary production. Estuaries, being open-ended and subject to tidal flushing, are highly dependent upon a continuous import of nutrients to maintain their productivity. Under circumstances of an oversupply of nutrients, however, the normal rate of primary productivity is altered and changes in structure and function of the ecosystem result.

The most obvious symptom of increased nutrient input is the often-cited bloom of certain types of algae. This is usually manifested by the rapid growth of the few species capable of rapid utilization of the incoming nutrients. The result is the competitive exclusion of many species present under more normal conditions. When these imbalances in the primary producers occur, entire food chains may also be altered and the secondary production prized by man may decrease.

Algal blooms may also lead to more subtle changes in the ecosystem. Decomposition of the dying and sinking bloom organisms results in low oxygen conditions, especially in areas of slow flushing, which lead to fish kills and destruction of benthic populations. Some algae prominent in blooms (e.g., some blue green algae) are little utilized by consumer organisms; these may also clog gills of animals. Shading occurs in bloom conditions and the photosynthetic activity of bottom plants is affected (e.g., several instances have been reported of grass flats being replaced by phytoplankton in cases of high nutrient input).

Estuarine waters are a mixture of sea and fresh water. As seawater contains large amounts of a mixture of salts, most of the salts necessary for plant growth, such as potassium and sodium, will be plentiful. Also, there will be no lack of the trace elements, such as molybdenum or cobalt, that often limit photosynthesis in oligotrophic lakes (Goldman, 1972). Two nutrients that are low in concentration in both sea and fresh water, nitrogen and phosphorus, have been shown to control productivity in estuaries. Consequently, we will consider only phosphorus and nitrogen in the following pages.

Objectives

1) To identify the sources and characteristics of nutrients entering the estuaries of the U.S.;

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2) To characterize the transport mechanisms for nutrients entering estuaries;

3) To summarize the impact and fate of nutrients in the estuarine ecosystem, both physical and biological;

4) To identify control mechanisms and evaluate them in terms of estuarine management; and

5) To recommend future programs of control and management.

SOURCES OF NUTRIENTS

Estuaries receive nutrients in both dissolved and particulate forms. Almost all of these nutrients enter the estuary in streams and rivers; a small amount also comes from precipitation and from the ocean. These relative proportions will be different in different reaches of an estuary so that at the mouth, for instance, most of the nutrients may have come from seawater (a large volume offsets the small concentrations). In this dependence on outside sources of nutrients, estuaries resemble lakes and rivers. All these systems contrast with forests or crop lands where some nutrients are constantly supplied from breakdown of the parent rocks and from the soils.

In forests and grasslands undisturbed by man, the soils and vegetation combine to conserve the nutrients in the watershed and allow only small amounts to leave in the streams. One example of this comes from a New Hampshire forest where more nitrogen and phosphorous entered the watershed in the rainfall than left by streams (Table 1, Table 2). Hobbie and Likens (1973) mentioned that while only 21 g P/ha left the watershed, some 1900 g P/ha were contained in the annual leaf-fall alone.

Table 1.—Inputs and outputs from the Hubbard Brook Experimental Forest* (from Deevey 1972, Table 2)

	Weighted av. conc. 1963/1969 (mg liter^{-1})	Average all undisturbed watersheds 1963/1969 (kg ha^{-1}yr^{-1})	
		Input	Output
Ca^{2+}	0.21	2.6	11.8
Mg^{2+}	0.06	0.7	2.9
Na^{+}	0.12	1.5	6.9
K^{+}	0.09	1.1	1.7
Cl^{-}	0.42	5.2	4.9
SO_4^{2-}	3.1	38.3	48.6
NH_4^{+}	0.22	2.7	0.4
NO_3^{-}	1.31	16.3	8.7
SiO_2	<0.1	**	35.1
Al^{3+}	—	**	1.8
HCO_3^{-}	0	**	14.6

* Sample data from Likens et al. (1971).
** Not measured but very small.

Table 2.—Input of phosphorus in precipitation and output in streams from watersheds 2 (deforested) and 6 from 1 June 1968 to May 31, 1969 (in g P ha^{-1}yr^{-1}). The output is given as the sum of the total dissolved phosphorus (TDP) plus fine particulate phosphorus (FPP) and as large particulate phosphorus (LPP) which is the sum of the phosphorus in inorganic particles plus that in organic particles > 1 mm (from Hobbie and Likens, 1973, Table 3)

	W-2	W-6
Input	99*	108*
Output		
TDP + FPP	20	9
LPP	183	12
Net gain or loss	−104	+87

* Estimated on the basis of precipitation analyses during 1971–1972, when the weighted concentration was 8 ug P liter^{-1}.

When the forests are cut, then the nutrient loss increases. For phosphorus, this loss doubled for the dissolved P in Hubbard Brook but increased fifteenfold for the P in particulate matter (Table 2). The nitrogen also increased drastically (36-fold) in Hubbard Brook after the forest was cut (Borman et al. 1974), mostly as dissolved nitrate. It is true of soils in general that phosphorus is strongly attached to soil particles and is lost from soils mainly by erosion of the particles themselves. In contrast, nitrate nitrogen is soluble in the soil water and is lost by percolation.

Much of the nutrients entering the freshwater streams and rivers of the U.S. come from sewage and agricultural wastes. The nutrients in sewage arise from human wastes, detergents, street runoff, and industrial wastes. There are a number of detailed studies of the amounts contributed by each source; an idea of the magnitude of the problem may be gained from the summary of Vollenweider (1968) for average conditions in central Europe (Table 3) and from Jaworski, Lear and Villa (1972) for the Potomac estuary (Table 4). The actual concentrations of nutrients in a given river will vary according to such factors as volume of flow, number of cities, amount of forest, and type of agriculture. High concentrations of nutrients are added by point sources, such as domestic sewage and industrial wastes (domestic sewage contains 1 to 4 g P/person/day and 5 to 15 g N (Vollenweider, 1968)). The concentrations of nutrients from nonpoint sources, such as farms and forests, is low but the total amount added will often equal or exceed that from point sources (Table 3). Thus, Vollenweider states that a lightly fertilized pine forest may receive 2 kg P/ha and 26 kg N/ha each year while heavily fertilized farmland may receive 37 kg P and 340 kg N. Between 10 and 25 percent of the nitrogen and 1 and 5 percent of the phosphorus will enter the streams from this fertilized land.

Table 3.—Amounts of nitrogen and phosphorus (kg/ha/yr) in runoff from an average area (from Vollenweider 1968). The range for farmlands and meadows and grassland reflects differing amounts of fertilizer reaching the streams

Sources	N	P
	kg/ha/yr	
Sewage		
Human wastes	6.6	0.8
Detergents	—	0.4
Street runoff	0.7	0.1
Industrial wastes	0.7	0.1
	8.0	1.4
Agricultural and Forest Runoff		
Arable land	2.3–5.8	0.1–0.5
Meadows and grasslands	4.3–13.3	0.1–0.5
Forests	1.0	0.1
	8.6–20.1	0.3–1.1
Total	16.6–28.1	1.7–2.5

Table 4.—Summary of nutrient sources, upper and middle reaches of the Potomac estuary (from Jaworski et al. 1972, Table 3)

	Land runoff (kg day^{-1})	Wastewater discharges (kg day^{-1})	Air-water interface (kg day^{-1})
Low-flow conditions (Potomac River discharge at Washington, D.C. = 33.98 m^{3}sec^{-1})			
Carbon	77,100	72,600*	431,000**
Nitrogen	3,040	27,200	726**,***
Phosphorus	454	10,900	0
Median-flow conditions (Potomac River discharge at Washington, D.C. = 184.06 m^{3}sec^{-1})			
Carbon	159,000	72,600	431,000
Nitrogen	18,100	27,200	726
Phosphorus	2,400	10,900	0

* Of the 72,600 kg day^{-1}, 27,200 kg day^{-1} are discharged as inorganic carbon.

** The potential CO_2 obtainable from the atmosphere was determined by using only 0.1% of the transfer rate of 0.8 mg cm^{-2} min^{-1} as indicated by Riley and Skirrow (1965).

*** Based on a nitrogen fixation rate of five lb acre^{-1} yr^{-1} as reported by Hutchinson (1957).

Seawater is also a source of nutrients in estuaries. It is usually considered that the reverse is true, and little thought is given to input from the ocean. As will be discussed later, however, a number of processes in estuaries will concentrate nutrients from water so even the nutrient-poor ocean water may lose some P and N to estuaries. In one estuary in Scotland, the Ythan, 70 percent of the P and 30 percent of the N that flow into the estuary were marine in origin (Leach, 1971) but the distribution of the P and N retained was not measured.

TRANSPORT OF NUTRIENTS

After the nutrients enter streams and rivers, some fraction may be changed by various processes before they finally reach the estuary. One process is the absorption by plants and bacteria; another is the absorption by sediments. The total quantity absorbed is difficult to quantify and it is also possible that some of the absorbed material eventually reaches the estuary (e.g., by washout during exceptionally high discharge). In the Upper Potomac Basin (Jaworski, Villa and Hetling, 1969), 38 percent of the phosphorus entering the surface waters is retained in the channel. The high nutrients in the water and the rich sediments will cause a dramatic increase in the aquatic plants (Fig. 1).

Another factor causing loss of nutrients in streams is adsorption onto particulate matter. Jaworski et al., (1972) states that more than 20 percent of the reduction of phosphates measured during peak flows could be attributed to adsorption followed by sedimentation of the particulate.

Nitrogen in land runoff enters the rivers and streams mostly as nitrates; however, the nitrogen from wastewater enters mostly as ammonia. This nitrogen is taken up by algae and other plants, is deposited on the bottom (as organic nitrogen after death of algae and plants), and is oxidized to nitrite and nitrate by nitrifying bacteria. In the Potomac

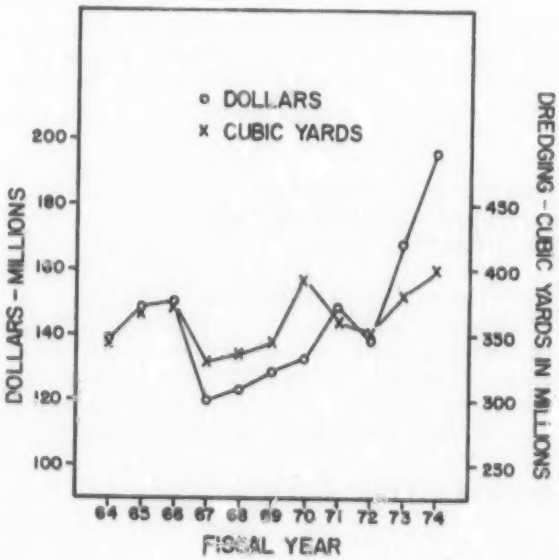

FIGURE 1.—Phosphorus, nitrogen, and organic carbon in the upper Potomac River from 1913–1970. The top line gives plant nuisances (from Jaworski, Lear, and Villa, 1972, Fig. 7).

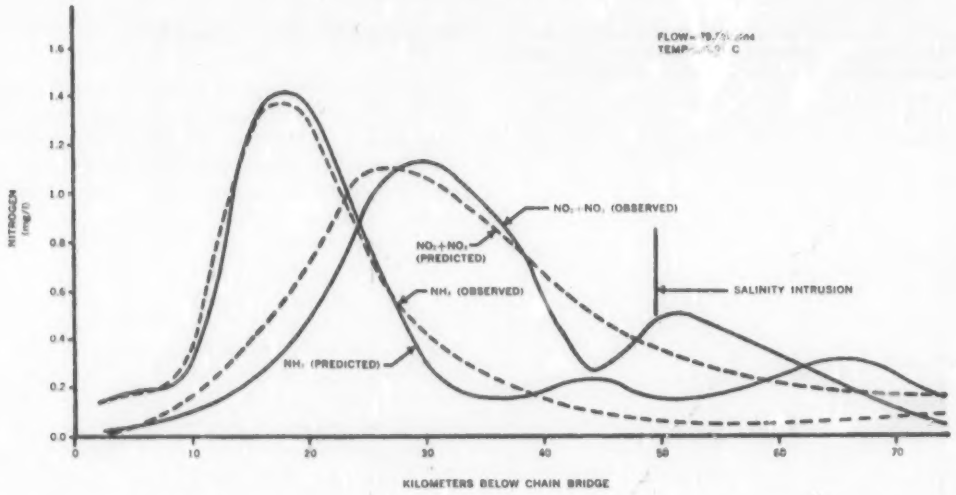

FIGURE 2.—The average and predicted concentrations of ammonia and nitrite plus nitrate in the Potomac River on August 17–22, 1968. The brackish water begins at about 50 km (from Jaworski et al., 1972, Fig. 12).

River the nitrification is the dominant reaction and most of the nitrogen is changed to nitrate (Fig. 2).

In some rivers that traverse coastal plains, such as the Chowan River in Virginia and North Carolina, the flood plain of the river is often flooded and the swampy ground resembles a giant sponge. Tremendous amounts of water flow in and out of these swamp soils as the water level in the river rises and falls due to flow and wind effects. The change in water level in the soils is easily measured 1 km from the river. The effect of this exchange of water on the concentration of nutrients is unknown but soils and peats do act as ion exchange columns and there are undoubtedly many changes occurring.

PROCESSES AFFECTING NUTRIENT CONCENTRATION IN ESTUARIES

A number of distinct processes change the concentrations of nutrients in estuaries. Most of these are acting simultaneously in most cases, but sometimes one process predominates. Thus, although the processes are described below in isolation, we do not mean to imply that only one process is occurring.

Physical and Chemical Processes

DILUTION

The circulation of estuaries causes a continual inflow of seawater and continual mixing with fresh water. If this were the predominant mechanism changing the concentration of the nutrients, then their concentrations would decrease in direct proportion to the increase in salt concentration. (The assumption that the ocean water has a lower concentration of nutrients than the fresh water is almost always valid.)

One estuary where dilution is important is Charlotte Harbor, on the west coast of Florida. Here, water from the Peace River, one of three rivers emptying into the estuary, contains 0.6 mg P/liter. This phosphate comes from phosphate mines and so there are no accompanying high amounts of nitrogen. Therefore, there are no algal blooms and the phosphate remains in the water (Alberts et al., 1970). As seen in Figure 3, the decrease in P concentration closely follows the ideal dilution curve indicating that neither biological nor chemical processes are important.

ADSORPTION AND COMPLEXING

Some of the nutrients entering estuaries are attached to particulate materials in the rivers. This is particularly true for phosphate and, to a lesser extent, ammonium. Most of the research has been carried out on phosphate.

When phosphorus is added to stirred suspensions of estuarine sediment, half of the phosphorus is adsorbed to the particulate matter within 15 seconds or so (Pomeroy, Smith and Grant, 1965). Much of the particulate matter is clay and silt and the adsorption properties of clay are well known. Evidence exists that some of this phosphorus may

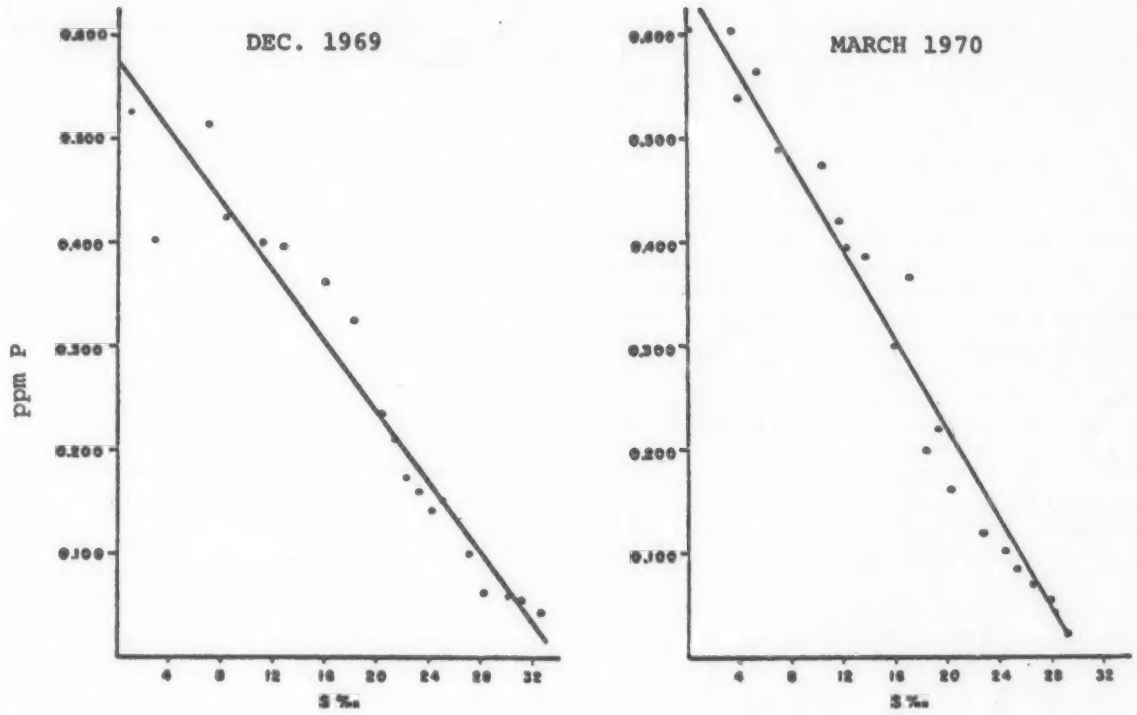

FIGURE 3.—Phosphorus concentrations and salinity in Charlotte Harbor, Fla. An ideal dilution curve is given as a solid line while actual measurements are plotted as dots (from Alberts et al, 1970).

be released or displaced by competing ions, such as chloride or sulfate, when the particulate matter reaches brackish water (Upchurch, Edzwald and O'Melia, 1974).

There also appears to be a good correlation between the amount of phosphorus and the amount of extractable (with oxalate) iron in estuarine sediments; this leads to the hypothesis that phosphorus can also be bound to particulate matter as a part of a phosphorus-iron-solids complex (Upchurch et al., 1974).

COAGULATION AND SEDIMENTATION

When the nutrient-rich river water reaches the upper parts of the estuary, the current slows as the river broadens. As a result, there is a rapid sedimentation of particulate matter and also of the phosphorus complex mentioned above. This sediment is very phosphorus rich (Fig. 4, the sediments above the 7 mile sample).

Some of the particulate matter is colloidal (i.e., small particles with a large surface area per unit mass). Typically, these colloidal particles are clays with an electrical charge. In fresh waters, the particles are kept from aggregating by repulsive forces, but when the particles move into brackish water the ions affect the particles and flocs are formed. The size and settling velocity of these flocs may be several orders of magnitude larger than those of the individual particles (see Edzwald, Upchurch and

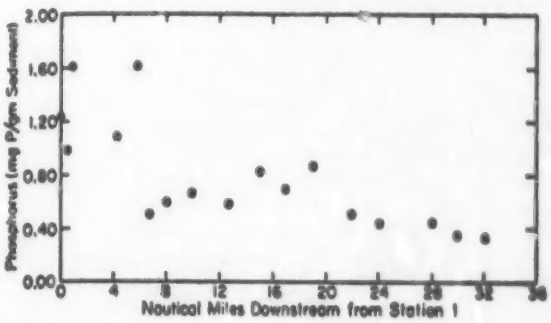

FIGURE 4.—The amount of phosphorus extracted from sediments by acid treatment (available phosphorus) as a function of distance downstream from the freshwater end of the Pamlico River Estuary (from Upchurch et al., 1974, Fig. 2).

O'Melia (1974) for a detailed description). In the Pamlico Estuary (Fig. 4), the decrease in P in the downstream sediments is possibly caused by coagulation and release of some of the phosphorus when the salinity of the water increased.

Although coagulation undoubtedly occurs in estuaries, it is a process that is easy to demonstrate in the laboratory and difficult to study in the field. In natural waters, organic colloids are present in addition to the clay colloids as well as some mixtures of the two. In addition, the adsorption sites on the clays in nature may be filled with a variety of ions both organic and inorganic. Thus, Button (1969) found that natural particulate material did not absorb small molecular weight organic compounds. Finally, other processes may be acting that obscure the coagulation effects. In the study shown in Figure 4, for example, large populations of clams are present in the upper parts of the river that may be just as effective in removing the particulate matter from suspension as the coagulation process.

No matter what the exact mechanism may be, the amount of nutrients deposited in the sediments of an estuary is high. For example, in upper Chesapeake Bay, Carpenter, Prichard and Whaley (1969) measured a loss of some 45 ug-at of nitrate nitrogen/liter (610 ug NO_3-N) during the late spring and summer or 450 mg-at/m^2 at the mean water depth of 10 m. They calculated that the annual sedimentation rate of 1 mm per year would add 500 mg-at/m^2 of nitrogen to the sediments. Thus, the loss of nitrogen was accounted for by the sedimentation (the authors regard the close agreement as fortuitous, however, as the sedimentation rate cannot be determined very precisely).

Equilibrium Between Sediments and Water

Not only do particulate matter and estuarine sediments remove phosphorus from solution, but they also release phosphorus back to the water. Thus, Pomeroy et al., (1965) showed that surface sediments acted as a giant buffer or reservoir for phosphates (Table 5). When the phosphorus in the water was less than about 0.9 ug-at/liter (28 ug P/liter), then phosphorus was released from the sediments to the water. Higher concentrations were absorbed by the sediments. Thus, these particular sediments were in equilibrium with water containing 0.7 to 0.9 ug-at P/liter.

This equilibrium level is somewhat higher than other values for fresh water but this will depend upon the type of sediments, previous history, pH, et cetera. It should be noted that recent studies by

Table 5.—Influence of suspended sediments on estuarine water of varying phosphate content. Final phosphate values are mean ± one standard error of the mean. Phosphate in μmoles/liter, 5 March 1964 (from Pomeroy et al. 1965, Table 1)

Initial PO_4^{3-} of water	Final PO_4^{3-} of water	PO_4^{3-} in sediment (μg PO_4^{3-}/g dry sediment)	n
0	0.72 ± 0.03	−1.0	7
0.5	0.73 ± 0.02	−0.4	4
1.0	0.90 ± 0.07	+0.6	8
2.5	0.89 ± 0.05	+7.6	8
4.3	0.97 ± 0.002	+11.0	8
8.4	1.61 ± 0.22	+30.9	3

Lean (1973) and others show that the exchange of phosphorus between the soluble and particulate forms is really quite complex. Low-molecular weight phosphorus compounds and colloidal phosphorus may be involved as well as the particulate and dissolved inorganic fractions.

While it is likely that many of the same reactions and processes are occurring with nitrogen compounds, these interactions of nitrogen and sediment have never been investigated in detail. One reason for this is the great difficulty in techniques; there is, for example, no radioisotope of nitrogen and use of the stable isotope ^{15}N requires elaborate instrumentation and a mass spectrometer. Another reason is that phosphorus is much more important in the eutrophication of fresh waters and much of the research has centered on lakes.

The Estuarine Nutrient Trap

There is always some upstream movement of seawater or diluted seawater in estuaries; otherwise there could be no salty water in the upstream areas. In certain estuaries with a high freshwater runoff, a shear zone is maintained for long periods with fresh water or low salinity water on top moving downstream and more saline water on the bottom moving upstream. If nutrients are moving vertically from the top to the bottom layers, by sinking or migration of the organisms, then the bottom waters will be enriched with nutrients that otherwise would be lost from the estuary. Also, the bottom waters will be enriched because of decomposition of organic particulate matter in the surface sediments. The theory of this nutrient trap is given in detail by Redfield, Ketchum and Richards (1963).

A good example of this countercirculation comes from the Gulf of Venezuela (Fig. 5). The seawater, containing about 0.5 ug-at P/liter, moves into the shallow waters of the gulf. As it does so, it accumulates phosphorus (up to 1.0 ug-at P/liter). An

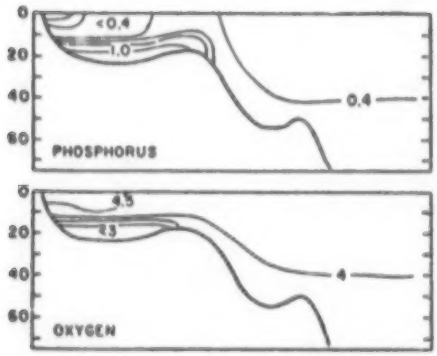

FIGURE 5.—The distribution of total phosphorus and oxygen in a section along the axis of the Gulf of Venezuela (the depth is in meters). From Redfield et al., 1963, Fig. 11.

example of this type of circulation producing a sediment trap comes from upper Chesapeake Bay (Schubel, 1968). Sediments were kept in suspension in this part of the bay by tidal currents that mix the water column twice each tidal cycle and also transport the turbid matter upstream in the bottom waters.

Although the nutrient trap certainly exists in estuaries, its importance for the annual nutrient budget has not yet been proven. Thus, in Long Island Sound, Riley and Conover (1956) and Harris (1959) measured accumulations of phosphorus and nitrogen in the summer but also found comparable losses during the winter. In estuaries at Sapelo Island, Ga., Pomeroy et al., (1972) found no nutrient trap operating.

Biological Processes

BIODEPOSITION

A number of biological processes are also removing particulate matter and its associated nutrients from solution. This biodeposition may even be more important than the physical-chemical processes already discussed. Van Straatan and Kuenen (1958) found that dense populations of molluscs filtered clay from the water and produced pellets and flakes which then behaved like sand grains. Organic detritus also trapped clay particles and the resulting flocs settled faster than those formed by coagulation. In a more quantitative study, Lund (1957) calculated that oysters filtered and deposited eight times the volume of sediment deposited by gravity alone. In fact, the deposited material was enough to completely cover the oysters in 36 days.

From tables given in Chestnut (1974), the biodeposition rate of the oyster is around 1.5 g dry wt/individual/week. If the amount of suspended solids is 5 mg/liter, this represents a minimum of 300 liters of water filtered per week. Jorgenson (1952) gives a rate of 10 to 15 liters per day per animal which would be a slower rate than the 300 liter value. Certainly, a tremendous amount of water is processed by an oyster bed; when this oyster filtering is added to the activity of other filter feeders, it is enough filtering activity to process the whole of the volume of an estuary in a matter of days or a few weeks.

The large rooted plants of estuaries also act as traps for the sediments, both by catching fine sediments (Van Straatan and Kuenen, 1958) and by providing protection (e.g., mangroves) so that the sedimentation rate is increased in the calm water. Various invertebrates and even diatom algae also secrete mucus or slimes that trap sediments.

The net result is that estuaries in general and marshes in particular act as giant filters to remove particulate materials from the water. The vegetation of the marshes also stabilizes the sediment and thus reduces the turbidity (Odum, 1970). The importance of these processes is illustrated by the rapid siltation that took place in many harbors in southeastern England when the marshes were first diked and filled (Gosslink, Odum, and Pope, 1974). In the U.S., Port Tobacco on the Potomac is now landlocked but received large sailing vessels during colonial times (D. Flemer, personal communication).

UPTAKE BY ORGANISMS

There are four main types of photosynthetic organisms in estuaries, rooted plants, attached algae, phytoplankton algae and sediment algae. The most obvious plants are the marsh grasses and rushes (e.g., *Spartina* and *Juncus*). These plants take up nutrients only from the sediments (Broome, 1973) so are not in active competition with other primary producers for nutrients. As noted, their presence creates conditions favoring sedimentation and biodeposition (e.g., the mussels in salt marshes). These plants also tie up a tremendous quantity of nutrients. For example, the annual production of organic matter in a Georgia *Spartina* marsh is 1600 g/m² (Cooper, 1974). Assuming that 44 percent of this is C and a C:N:P ratio of 125:2:0.3 for *Spartina* (Thayer, 1974) gives 11.3 g N and 1.7 g P/m². Even more is tied up in roots and rhizomes.

In some areas, submerged eelgrass (*Zostera*) [illegible] n important primary producer. Williams (1973) estimates that eelgrass may supply as much as 64 percent of the total production of phytoplankton,

Spartina, and eelgrass in the shallow estuaries near Beaufort, N.C. This may be 350 g C/m²/yr and other plants in the eelgrass beds (*Halodule* and *Ectocarpus*) may produce another 300 g C.

Attached algae are not important generally in estuaries because the soft substratum and the tidal flooding of the marshes do not offer a suitable habitat. Permanently submerged plants, on the other hand, accumulate a thick layer of attached algae (reds and browns) as they grow. Measurements of the primary productivity of these algae show a photosynthesis rate equal to that of the *Zostera* (P. Penhale, personal communication).

Microscopic algae also live in the upper layers of the mud. When these are extensive mud flats, such as in the Georgia salt marshes, the primary production may be as high as 420 g C/m²/yr (see summary by Cooper, 1974).

Phytoplankton algae are not abundant in many estuaries (Table 6) because of rapid flushing and high turbidity. Yet, they may be the most important food for zooplankton and invertebrate larvae (Odum, 1970). In very large estuaries, such as Chesapeake Bay, there is adequate time for the algae to develop and primary production may reach several hundred g C/m²/yr (Flemer, 1970).

The well-known efficiency of algae in taking up nutrients from even very nutrient-poor waters, means that they will be an agent for removing nutrients from the water of the estuary. This can come from death and sinking to the sediments, from the filtering action of benthic worms and molluscs, from being eaten and carried away by migrating fish, or from washout from the estuary when strong tides are present.

Green plants are not the only organisms removing nutrients as bacteria are also important. The only quantification of this comes from the work of Thayer (1974) who pointed out that the *Spartina* has low amounts of N and P relative to the C (see ratio above) while bacteria need a C:N:P ratio of 200:10:1 for their growth. Thus, bacteria decomposing the *Spartina* must get the additional N and P they need from the surrounding water. Thayer (1974) also showed that the bacteria out-competed the algae for these nutrients and suggested that the bacterial immobilization of nutrients might be a major cause of the extremely low levels of nutrients found near Beaufort, N.C.

Table 6.—Organic carbon production (g C/m²/year) in salt marshes and adjacent estuaries at Sapelo Island, Ga., and near Beaufort, N.C. (from Cooper, 1974; Williams, 1973)

	Georgia salt marsh	Beaufort shallow estuary
Salt marsh	700	256
Submerged plants	—	650
Attached micro algae	—	350
Mud algae	420	—
Phytoplankton	—	66

NUTRIENT CYCLING

Once nutrients reach the estuary and either are transported to the sediments or are taken up by the biota, they can cycle through various compartments before being locked into the sediments or flushed out of the estuary. For example, *Spartina* is tall near the creek banks where fresh sediments are continually deposited but short farther from the creek. Broome (1973) traced this effect to deficiencies of N in the sediments away from the creeks. Once the nutrients are taken up into the plant, part is used for growth, part is excreted or otherwise lost from the plants, and part is eventually released during decomposition. Some of the complex of reactions occurring in a *Zostera* bed are given in Figure 6 where 166 mg P/m²/day are absorbed from the sediments and 62 mg P excreted into the water.

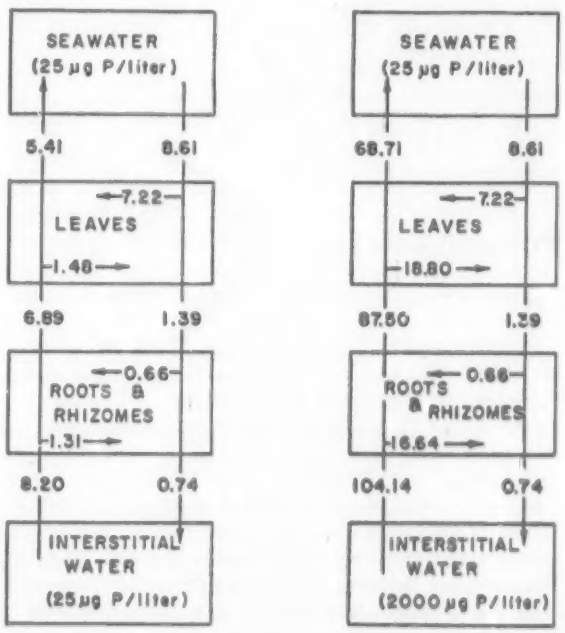

FIGURE 6.—Calculated daily phosphorus flux through 1 g dry wt. of eelgrass. Left: uniform dissolved reactive phosphorus concentration in water. Right: phosphate gradient similar to the natural environment. Units are ug P/g plant-day (from McRoy et al., 1972, Fig. 7).

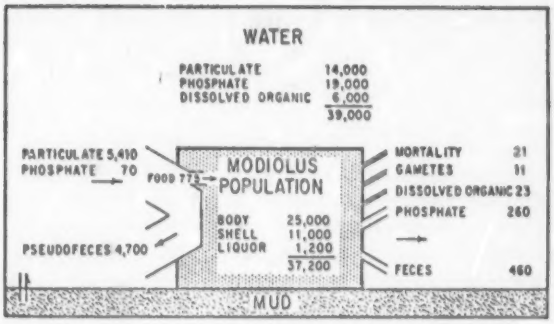

FIGURE 7.—Diagram of phosphorus flow through the mussel population. Values for the water and the mussel population are ug P/m² day. The flux rates of phosphorus in food and pseudofeces are calculated values necessary to balance the other, measured flux rates.

Table 7.—Some contributions to the net increase or decrease of inorganc nitrogen that occurred within the Pamlico River Estuary

Increase (metric tons N day⁻¹)	Decrease (metric tons N day⁻¹)
February 1972: net increase of 6.91 metric tons N (day⁻¹)[a]	
1. Sediment release—0.52	1. N assimilation—6.68
2. Rainfall —0.11	
0.63	6.68
August 1972: net increase of 0.10 metric tons N (day⁻¹)[a]	
1. Sediment release—3.43	1. N assimilation—231.65
2. Rainfall —0.71	
4.14	231.65

[a] Calculated from inputs minus output.

Algae and bacteria also excrete phosphorus (Kuenzler, 1971). The phosphorus budget for a salt marsh mussel (Kuenzler, 1961) illustrates that the large amount of P cycling through the animals is about equal to the quantities moving into the plants (Fig. 7).

Nitrogen also cycles in the estuary. The general pattern is for nitrate to enter the estuary (see Fig. 2) and be rapidly removed from solution. Ammonia is continually being formed (by decomposition processes and NO_3 reduction) and taken up so its concentration does not change very much. Organic nitrogen excretion and decomposition products are also continually cycled through the sediments and water. In the Pamlico River Estuary, for example, Harrison (1974) found that urea wes recycled every 1.4 days in the summer and every 200 days during the winter. His budget for N in this estuary (Table 7) indicates that during a winter month the N assimilated during photosynthesis was balanced by the N (mostly NO_3) left in the estuary as the water flowed through (here, this is given as a net increase of 6.91 tons). The budget is badly out of balance during the summer, however, and it is likely that ammonia recycling in the water column and coming from the sediment made up the discrepancy of 227.5 tons/day. Similar recycling in the upper waters was measured by Carpenter et al., (1969) in Chesapeake Bay. Thus, the observed photosynthesis rate would result in a recycling of N and P every 1 to 4 days. Because of the large number of zooplankton present, they thought that the algae were being controlled by grazing.

It is reasonable that marshes are nutrient sinks as they usually accumulate organic matter which, in turn, contains nutrients. The actual evidence for this is divided, however. Byron (personal communication) found a 40 percent reduction in nitrogen leaving a salt marsh compared with the amount entering on the flood. In contrast, Heinle et al., (1974) found that the net annual flow of N, P and C was from the marsh to the estuary while the chlorophyll pattern was the reverse. Marshall (1970) reported that marshes treated with sewage retained large quantities of N and P.

Finally, nitrogen may be lost from the estuaries, and particularly from the marshes, by denitrification. This is an anaerobic bacterial process that requires NO_3 and energy in the form of organic molecules. Both denitrification, and the opposite process, nitrogen fixation, are occurring in estuaries but their importance, judging from only a little data, is likely small.

Estuarine Responses to Nutrient Additions

In a review of the literature on estuaries that receive sewage wastes, Weiss and Wilkes (1974) concluded that hydrographic conditions, particularly the rate of flushing, was the most important factor determining the response of the ecosystem. An estuary with rapid flushing can handle tremendous amounts of added nutrients as long as they are quickly transported away and quickly diluted with low nutrient ocean water.

MORICHES BAY AND GREAT SOUTH BAY, LONG ISLAND, N. Y.

The first example, from Ryther (1954) and Ryther and Dunstan (1971), describes two connected embayments, Moriches Bay and Great South Bay. Duck farms around Moriches Bay formerly fed

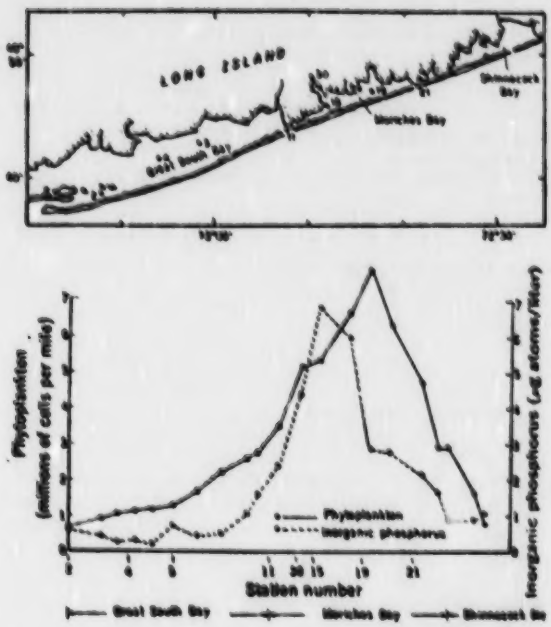

FIGURE 8.—The distribution of phytoplankton and inorganic phosphorus in Great South Bay, Moriches Bay, and Shinnecock Bay, Long Island, in the summer of 1952. Station numbers on the map (above) correspond to station numbers on the abscissa of the figure (right) (from Ryther and Dunstan, 1971, Fig. 1).

wastes into the bay. These nutrients reached Great South Bay which has a retention time of one month. This bay formerly had good stocks of fish and shellfish but the fishery began to decline in the early 1940's as the duck population increased. At the peak of the algal blooms, their numbers declined on either side of the Moriches Bay peak (Fig. 8).

Laboratory and field tests showed that the algae were actually limited by the low nitrogen which was used up almost as soon as it entered the estuary. The damage to the oysters came from a shift of phytoplankton from a mixed group of species dominated by diatoms to two small forms, *Nannochloris* and *Stichococcus*. Although oysters will eat these forms, these algae are nutritionally inadequate. Another factor adversely affecting the oysters was the large production of Serpulid worms which were able to overrun the oyster beds and competitively exclude the oysters.

PAMLICO RIVER ESTUARY, N. C.

A second example comes from the Pamlico River Estuary in North Carolina (Hobbie, 1974). The cities on the Tar River, the main influence, are relatively small but a great deal of nutrients enter the Tar from agricultural runoff, presumably from heavily fertilized tobacco, potato, corn, and soybean fields. The total phosphorus entering the estuary ranges from 2.4 to 6.3 ug-at P/liter (74 to 195 ug P/liter) while the reactive P ranges from 0.4 to 4.1 ug-at P/liter (12.4 to 127 ug P/liter). There is always adequate phosphorus in the estuary and also enough ammonia. There are tremendous blooms of dinoflagellates (esp. *Peridinium triquetrum*) in the middle reaches of the estuary (Fig. 9) in the winter months (January until April) whose occurrence is apparently triggered by the winter influx of nitrate nitrogen into the estuary (Fig. 10). It should be noted that any chlorophyll concentration above 15 is an algal bloom.

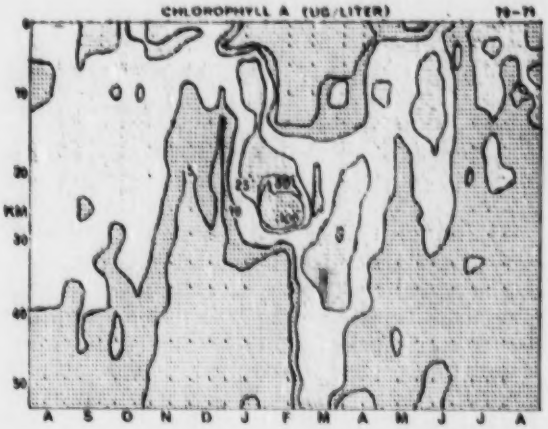

FIGURE 9.—Chorophyll *a* (ug/liter) in the Pamlico River Estuary for 1970–71. Distance is in km from Washington, N.C. (from Hobbie, 1974, Fig. 55).

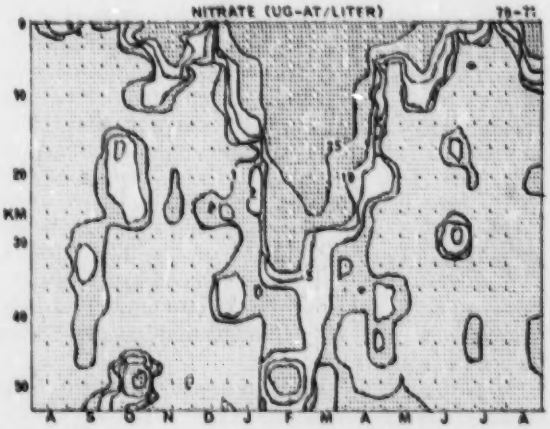

FIGURE 10.—Nitrate (ug-at N/liter) in the Pamlico River Estuary for 1970–71 (from Hobbie, 1974, Fig. 38).

The ecological effect of these blooms is slight so far. The estuary still harbors a commercial blue crab and shrimp industry and the benthic biota is diverse. The one well-documented result of the rich conditions is that areas of low oxygen bottom water do develop now and then during calm periods of the summer. These only last for a few weeks but do kill all the bottom fauna in the central part of the estuary each year (Tenore, 1972). Another minor effect is the apparent increase in filamentous algae. In summary, this estuary has reached a high level of production but the species are unchanged. The only effect is an indirect one by way of the sediment and their increased oxygen uptake during periods of low flow and calm conditions.

Concluding Statement

In these two examples it may be seen that the flushing of the estuary plays a central role in allowing the effects of high levels of added nutrients to be expressed. In both cases, the nutrient levels were greatly above the levels that would have ruined any lake. From these findings, and from the experiments that successfully added sewage to salt marshes with little detrimental effects, we conclude that estuaries can handle large quantities of nutrients. They do this by removing most of the nutrients to the sediments (by sedimentation, coagulation, biodeposition, et cetera) where they serve to enrich salt marshes. In addition, three characteristics of estuaries (rapid flushing, dilution with low nutrient seawater, and quite a lot of turbidity) help prevent dense algal blooms from developing.

When the capacity of estuaries to handle nutrients is exceeded, algal blooms can result that seriously degrade the water quality. Moriches Bay has been mentioned and Back River, a tributary of Chesapeake Bay that receives Baltimore's sewage, is another example (Carpenter, Pritchard and Whaley, 1969). Where conditions are suitable, rooted plants may also reach nuisance amounts as was seen for the water chestnut in the 1920's and the water milfoil in 1958, both in Chesapeake Bay (Jaworski et al., 1972).

As noted, nutrients by themselves can adversely affect estuaries by supporting algal blooms and the deoxygenation that can accompany eutrophication. Perhaps of more importance are the organic matter, heavy metals, and pesticides that often enter estuaries along with the nutrients.

CONTROL MECHANISMS

Control at the Source

The potentially most successful and least harmful means of control of nutrient inputs to estuaries is to control the nutrients at their sources. Obviously, some sources of nutrients are more easily identified than others. Technology is available to institute control mechanisms for most point sources, but in some cases the costs are beyond social desires. In cases of non-point sources of nutrient pollution the technology for control has not become feasible. In these situations, effective nutrient control is possible through changes in land use, cultural practices, environmental manipulations, economics, and other management schemes.

Sewage Treatment

Since nitrogen and phosphorus concentrations in domestic sewage are rather high, sewage effluent constitutes an important source of nutrient materials (Table 3). Recent developments in technology, however, have made it economically possible to control the nutrient emissions from sewage treatment plants. In most instances, however, these technologies have not been utilized and large nutrient inputs are still occurring via sewage treatment plants.

Through the utilization of treatment technology and the enforcement of regulations, nutrient inputs from sewage treatment facilities can be controlled. Indiscriminate, blanket regulations, however, can be unnecessarily expensive when complete control is not needed. Thus, nutrient control at the sewage plant should be done on a case by case basis and be dictated by the location of the treatment facilities and the nature of receiving waters. For example, very high degrees of treatment and stringent regulations may be necessary in very sensitive and delicately balanced, protected systems. In contrast, less stringent treatment regulations are required in large, open, rapidly-flushed systems or in areas such as marshes where there are already storages of organic matter and nutrients.

Fertilization and Agricultural Practices

About one-third to one-half of the food and fiber production in the U.S. is attributed to the use of fertilizers in agricultural practices. Thus, the application of fertilizer to farmland is a necessity if we are to maintain the level of food production at present levels. Studies have shown, however, that

10 to 25 percent of the nitrogen fertilizer applied to cultivated crops leaves the field in drainage water. Thus, crop fertilization is a source of nutrients capable of flowing into estuaries. Heavy applications of fertilizers are applied to cultivated crops particularly in the coastal plains of the Gulf of Mexico and southeastern Atlantic areas.

Since the rate of food and fiber production in the U.S. must be maintained, application of less fertilizer is not likely in the near future. Possibilities of control at this source of nutrient inputs lie in the areas of agricultural practices and technological breakthroughs. One possibility is the utilization of cover crops during the non-cropping seasons to help hold the fertilizer in the soil layers. Other possibilities include timing and rates of fertilizer applications, repeated small applications and development of new crops. Of high potential for control of nutrient transport is the control of water drainage from fields by catchment basins, with re-percolation back into the fields between plowings. The very recent development of chemicals to control nitrifying bacteria, to prevent conversion of ammonia to nitrate, offers great hope for reducing nitrogen loss from fields. These chemicals help maintain the nitrogen in the form of ammonia (which has much greater potential for remaining in the soil than nitrate), and therefore allow reduced application rates of nitrogen fertilizer.

Animal production techniques are changing from small producers with several types of animals on pastures to intense production of one species in feedlots. Confinement has allowed increased and more economical production, but has also resulted in point sources of nutrient materials to surface waters. Although, because of convenience and economics, these materials are disposed of in liquid systems, land disposal is considered to be another feasible method of terminal disposal. In either situation, however, there is the potential for nutrient percolation to ground water and surface water runoff.

It is unlikely that conventional sewage treatment facilities will be utilized for animal waste systems within the near future. Therefore, the most likely means of immediate control of this nutrient source is in disposal practices. Some feasible alternatives include deep well injection, controlled land application, or recycling through newly-devised feed preparation systems. This area of activity, however, probably presents one of the more serious disposal problems facing present day technology.

Where large metropolitan areas are adjacent to coastal waters the practice of the suburban dweller "keeping up with the neighbors" and over-fertilizing his lawn presents a real nutrient input problem. With very little means of disposing of suburban runoff, the ultimate fate of that water is usually the adjacent surface waters. The main control mechanism available at the present time is to cycle these materials through municipal treatment plants.

Industrial Waste Treatment

Industrial wastes represent another large source of nutrients to surface waters and constitute another area where treatment technology is available for control. Advanced industrial waste treatment technology has been developed for the control of nutrient materials in most industrial wastes. The problem has been in instituting complete and proper waste control facilities in existing industrial complexes.

The runoff of nutrient materials from the surface areas of industrial complexes presents a separate problem in the control of nutrient sources. Mechanisms need to be developed for channeling this runoff through treatment or filtering systems to reduce nutrient inputs and drainage.

Runoff

One of the sources hardest to control is the runoff of materials from watersheds. This represents a very diffuse and highly variable source of nutrient materials but is, nevertheless, extremely important. The main possibilities of controlling nutrients from runoff involve watershed management.

Erosion control can prevent a large source of nutrients entering surface waters from watersheds. Carefully controlled forestry practices, reforestation, protection of uncovered areas, road maintenance, controlled drainage, vegetated filter strips, and contour plowing are management techniques currently available for erosion control.

Large areas of urbanized watersheds represent a tremendous source of nutrients and other materials. Catchment basins and storm drainage mechanisms are the best possibilities for control here.

Ground Water

Ground water as a source of nutrients for estuaries is not very well understood. Drainage of nutrient materials from septic tanks into ground water has been documented in several situations, particularly on the Barrier Islands along the U.S. seashore. Shallow ground water tends to percolate toward the inside of Barrier Island shores, thus,

leaking into estuaries and sounds. The best means of control under these situations is the central collection of waste waters and channeling through waste treatment facilities on a regional basis.

A problem that must be dealt with is the physical manipulations that allow alterations in ground water drainage patterns. For example, dredging deep channels in estuarine systems may enable groundwater percolation to bring in a new source of materials from outside the estuarine system. Considerable research must be conducted on this problem before the impact is understood or control legislation can be enacted.

Control of Transport Mechanisms

Control of nutrient inputs through manipulation of transport processes offers scant possibilities. There are some subtle changes that may be enacted in various physical processes. By and large, however, these may have little beneficial effect on the receiving system downstream because detrimental side effects may be greater than any benefit from nutrient control (e.g., reduction of vital freshwater inputs).

Stream Flow

Once nutrient materials reach the streams flowing into estuaries, institutional controls offer little benefit. Considerable evidence exists concerning decrease in nutrient concentrations downstream from sources due to deposition, biological cycling, and so forth, but additional control of nutrient inflows is not now technologically feasible.

Utilization of reservoirs on streams may offer some control benefits. Selective release of downstream water through reservoir dam structures can be used to regulate nutrient concentrations downstream.

Channelization

The increase in channelization of natural streams in recent years for the purposes of increased drainage and agricultural activities has changed normal stream flow mechanisms. Creating faster flowing streams has minimized the natural loss of nutrients as water meanders downstream. Channelization also allows the water to move downstream rapidly, thus avoiding the natural cleansing action by swamp soils around these streams where water normally percolates (see Transport of Nutrients).

Controlled transport of nutrients can be maintained if channelization procedures are closely regulated. For example, construction of low dikes or diversions to assure normal percolation can be beneficial. Considerable research needs to be done on this phenomenon before control mechanisms can be a significant factor on nutrient inputs into coastal systems.

Denitrification

Denitrification offers the best possibilities for the control of nitrogen during transport. Considerable reduction of nitrogen can be achieved if conditions are properly maintained over a time period. Holding drainage water from agricultural lands, for example, could be maintained so that favorable conditions could exist for denitrification (considerable research is underway in this area and still more needs to be done). The use of small reservoirs and low level dikes in some stream situations could be utilized in denitrification. Sewage holding ponds have long been utilized to achieve reductions in nitrogen concentrations in effluents. This technique has also been used for some industrial waste.

Within the Estuary

Control mechanisms for nutrient reduction within estuarine systems probably offer the least possibilities of effective reduction in nutrient concentrations. The worst problems include detrimental side effects, high costs, and interference with normal cycling procedures within the ecosystems. A few innovations, however, are worth looking into on a pilot study basis.

Selective Harvesting

Since certain organisms (e.g., species of algae during blooms) take up large amounts of nutrients, selective harvesting of these species serves as a means of removing the nutrients from the system. This technique, however, offers little hope for effectively removing nutrient materials from estuarine waters since the cost and engineering of such harvesting systems would be large. Natural means of doing this have been tried in several cases by culturing species of algae-utilizing fish, Manatee harvesting underwater grasses in Florida, culturing species of clams and oysters, and so forth. Estuaries are large dynamic systems, making this kind of control mechanism very difficult. Physical means, such as filtering algae and clipping higher plants, are expensive and ineffective.

DIVERSIONS

Creating canals to divert nutrient-laden water around estuarine systems is an unlikely means of control because of obvious side effects. There are several examples in the U.S. coastal area where large regional sewage interceptors are diverting large amounts of waste waters around estuaries for offshore disposal. These are expensive and, in some cases, deprive estuaries of the much-needed freshwater input and its flushing action.

ZONING

Estuaries in each state might be zoned so that some receive added nutrient input while others are protected. This means of control, however, assumes that decisions can be made concerning which estuaries receive added nutrients and which do not. Considerable research will be required before zoning can become a viable option.

IMPOUNDING

Construction of impoundments at the heads of estuaries offer some possibility for selective control of nutrient inputs into the large estuarine expanse. Impoundments offer the advantage of trapping water, allowing time for denitrification and deposition of phosphorus materials into the sediments, and selected withdrawal of water from the impounded area. This type of control, however, has serious side effects in that the normal flushing activity of freshwater inputs would be altered, possibly leading to severe changes in the estuarine system.

REGENERATION OF MARSHES

Marshes adjacent to estuaries are known to select nutrient materials from estuarine waters flushing over the marsh areas. The marsh system, with its grasses, algae and accumulated organic muds, acts as a filtering system to reduce nutrient content of the surrounding water. This, indeed, is one of the more beneficial roles of marshes as part of the estuarine system (i.e., maintaining the balance of nutrients and organic materials in estuarine waters).

The technology for regeneration of marshes has been worked out. Thus, it is possible to plant marsh grasses and generate new marsh area around estuarine shores. This may serve as an important means of controlling nutrients in estuarine waters and of creating desirable nursery habitat as well.

RECOMMENDED FUTURE PROGRAMS

Research Needs

DENITRIFICATION

Since nitrogen seems to be a major nutrient factor in estuarine ecosystems and it is difficult to control at point sources, denitrification offers many opportunities for the reduction of nitrogen compounds entering estuarine systems. The biological and physical aspects of denitrification processes are fairly well understood, but the conditions of natural systems necessary to control the processes are less well known. Utilization of sewage holding ponds has offered significant promise in aiding the denitrification process. These techniques have been expanded to include the waste from animal feed lots and industrial sources. The diffuse and harder-to-identify sources of nitrogen from agricultural practices, runoff, and ground water are places where denitrification processes offer considerable promise for imposing controls.

Experiments and pilot studies need to be conducted to determine natural conditions whereby denitrification can be initiated. For example, we need to know the length of time water running off and through cultivated fields needs to be impounded before denitrification is significant. Some work is being conducted now in North Carolina, Oregon and California on drainage water from fertilized fields.

NITRIFICATION

Since ammonia nitrogen has greater potential than nitrate for binding with soils and remaining on the fields, prevention of its conversion to nitrate (nitrification) could provide considerable promise for control of nitrogen loss. Chemical procedures to reduce nitrification, capable of widespread and effective use in agriculture, have been recently developed. Still unknown, however, are application procedures, timing of application, rates of application, economic returns, environmental impact of the added chemicals and cultural acceptance. If this process can be developed and utilized there can be tremendous reductions in nitrogen losses from fields through both prevention of nitrate formation and from reduction in fertilizer amounts needed to maintain productivity.

FORESTRY TECHNIQUES

Recent work has verified that nutrient materials in water running off deforested areas is higher than

water coming from similar forested areas. It is not known, however, how much vegetation needs to remain on the forest floor to hold the nutrient materials against runoff nor is it known what mechanisms are at work in adding the nutrients to runoff water. For example, decaying tree stumps on the forest land could aid in percolation of water into the soil, thus averting nutrient escapement from the forest lands. Well-vegetated filter strips adjacent to surface streams might help control the loss of nutrients from the watershed. These kinds of research activities could lead to considerable reduction in the amount of nutrient materials washing from the large expanses of forested areas, particularly in the southeastern section of the U.S.

FARMING ACTIVITIES

More research is needed to determine the optimum rates and timing of fertilizer applications to various crops. Although it is well understood that the use of fertilizer is necessary to maintain the production of food and fiber at the present level in the United States, it is possible that additional research could reveal means of preventing fertilizer loss from these crops. The use of certain types of cover crops during the non-cropping season might benefit the control of nutrient escapement. Controls of water tables, drainage procedures and harvesting activities need to be investigated.

The treatment and disposal of waste from animal feed lot activities need to be researched. It is already known that lagoons and oxidation ponds are very helpful in the reduction of nutrient concentrations and effluents, but the land disposal of these wastes still raises problems and the necessity for additional treatment is not known. Considerable interest has been recently generated for the recycling of wastes from feed lots back into the feed cycle and utilization of valuable nutrients as growth additives.

Research needs to be conducted on the ways and means whereby large areas of forested land are converted to agricultural lands by drainage and soil conditioning. Very little is known about optimizing the drainage patterns, density of drainage ditches, and vegetation belts around fields to reduce nutrient loss.

NATURAL FILTERS

The use of natural filters for decreasing nutrient loading in estuarine systems offers some possibilities, but research is needed before these can become a practical reality. Although regeneration of marshes is presently feasible, the positioning and physical arrangements of such systems need to be investigated before much practical judgement can be made. Utilization of attached algae and rooted plants in incoming streams and peripheries of estuaries for taking up nutrients might be a possibility if the biology and harvesting problems can be worked out. If harvesting techniques for algae could be developed, the use of certain species could be feasible for the removal of large amounts of nutrients from estuarine waters.

TREATMENT INNOVATIONS

Although technology for the removal of nutrient materials from sewage and industrial waste has been developed, the costs and hardware needed for this treatment level are often prohibitive. Thus, additional research needs to be conducted to find ways to reduce these costs and to provide means whereby siting benefits can be used.

New treatment technology needs to be developed for handling animal waste and drainage from agricultural areas. Deep well injection and land disposal of these wastes are presently being utilized without complete knowledge of the fate and changes in nutrient components of the waste.

Disposal of domestic and industrial waste into deep ocean waters is a popular remedy. Before this becomes more widespread and waste water criteria established, we need to know more about what kind of treatment is needed and the fate of these materials in the near ocean waters. Further, various innovations concerning the type of disposal conduits and outlets need to be investigated and realistic distances from shore for disposal need to be known.

ECOSYSTEM RESPONSE

In spite of the recent emphasis on the fate of nutrients in estuarine waters, we still lack considerable knowledge about the response of whole ecosystems to nutrient additions. We can predict certain algal blooms under certain conditions of nutrient inputs, but we fall dismally short of predicting the response of food chains and other ecosystem components to nutrient inputs. Can we, for example, under certain conditions of additional nutrient inputs expect larger fish yields in estuarine systems?

Since nutrient input controls make little sense unless the impact on the estuarine ecosystem is known to be detrimental, we need to develop better knowledge and predictability of these inputs on

various kinds of estuarine systems. More work needs to be done in the development of ecosystem modeling as it relates to nutrient flows and the use of microcosms for testing various practical theories.

Management Mechanisms

Point Sources

Although it is the aim of the Environmental Protection Agency to eventually control inputs at all point sources, it is necessary to initiate a management scheme to make this a reality. These management mechanisms may include the selection and mixing of different kinds of materials, particularly regulating nutrients into other selected inputs. For example, in certain instances auxilliary input of nutrient materials may be beneficial in establishing additional opportunities for selected harvesting, food production or ecosystem planning.

Some benefit may be obtained in regard to point sources of nutrient materials by the physical placement of the input mechanisms. For example, controlled point source release of nutrient materials in estuarine channels or into marsh systems may be a viable management technique.

Runoff

Management means to control the nutrient inputs from runoff involves a complicated and well devised management plan. A factor complicating management of watersheds for controlled runoff is the fact that most watersheds are owned by private citizens outside the jurisdiction of the water manager.

Nutrients from runoff are largely attached to or incorporated in particulate materials. Various mechanisms are available to control the removal of particulate matter, but programs of implementation and regulation need to be developed. For example, silt screens could be used in construction activities to capture particulate runoff and prevent it from entering surface waters.

Transport of sediments from the surrounding watershed to streams entering estuaries offers great potential for control. The sediment transport could be minimized by management techniques involving improved road maintenance practices, stabilization of uncovered land areas, and drainage of excess water through filter strips.

Development of vegetated filter strips adjacent to streams and estuarine shores would minimize the transport of nutrient materials into the surface waters. Changes in forestry and agricultural practices by private land owners can be a means of controlling runoff and possibly improving the economic return for the land owner.

Estuarine Modifications

In the management of estuaries, it may become desirable to modify inputs and components to maximize utilization of materials and productivity. If these action programs are to be instituted they should be identified as an example of a class of action and studied before and after the change so that we can obtain guidelines for future operations of this type. For example, the diversion of nutrient-laden input water over and through large, natural filtering systems in estuaries may be a viable possibility in estuarine management.

Recently the use of systems analysis and simulations have been effective in assessing management needs. Although it is necessary for the system as a whole to be managed to avoid detrimental side effects and to maximize system yield, simulations of component parts may be a powerful tool for achieving the goal. In managing estuaries in regard to the desirability of modifications, it is important that the scientific approach be combined with economic analyses to achieve some management optimization.

Land Use Planning

By examining the environmental characteristics of an area, land use planning can be delineated and used as a guide for locating various use categories. Most urban areas have adopted zoning ordinances and have developed procedures for exerting some control over their patterns of development, but outside the confines of these municipalities little has been done in terms of developing realistic planning. To make land use planning a reality in coastal systems, one must be able to combine and optimize the environmental needs with the economic needs.

Since the technology exists for controlling nutrient inputs at point sources, management of point source inputs is a matter of economics and enforcement. But, the non-point sources present a more difficult problem. Land use planning offers the greatest potential for controlling these non-point sources. Drawbacks include lack of knowledge in instituting a planned program and development of public trust.

Estuaries as Ecosystems

Any plans for the successful development, management and regulation of estuaries of the United States must be consistent with the ecological and

economic principles by which such systems operate, with and without man. Unlike normal land problems, estuaries are moving, dynamic systems influenced by inputs from every direction. For example, many maps from regional planning programs show their boundaries lying across bays and estuaries as if they were a piece of real estate. This is unworkable because any planning and management done on one side of the bay may be negated if something contrary is done on the other side of the bay. Any new legislation enabling planning and management schemes must allow authority over units of circulation if the management is to be scientifically sound. Until estuarine systems are recognized and planned as whole ecosystems, any management mechanisms brought to bear will be doomed to failure.

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ESTUARINE WASTEWATER MANAGEMENT: DESIGN CONCEPTS AND CONSIDERATIONS

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ABSTRACT

The design of estuarine wastewater management systems should consider the cost and effectiveness of specific pollutant removal (treatment), and the cost and efficacy of wastewater transport to and dispersion in areas of high dilution capacity, and of minimal ecological significance. A representative example cost analysis for a city of one million persons (wastewater flow of ~4.4 m^3/sec.) indicates that the incremental cost of upgrading treatment from secondary to advanced (tertiary) level is adequate to build and operate a land interceptor-transport system about 124 kilometers (~77 miles) in length. Similarly, for a coastal city (Pacific Coast conditions) the same incremental cost for upgrading treatment would build and operate (break-even basis) a deep water outfall-diffuser system about 28.0 kilometers (~17.2 miles) in length. If long-term protection of estuarine resources is to be achieved, all technical and economically feasible steps should be taken to transport adequately treated wastewaters out of estuarine systems, to the open coast in well engineered transport and high-dilution capacity outfall dispersion systems.

INTRODUCTION

Increasing concern about environmental quality coupled with limited factual information about waste discharge effects and a general ignorance of conventional wastewater treatment systems, contribute to increasing confusion in the development of estuarine and coastal wastewater management systems. Although this paper is concerned with estuarine wastewater management systems, it will be pointed out that one cannot rationally separate the estuarine problem from the broader question of coastal wastewater management. Unfortunately, all too often these two problems are treated separately, even by some evolving regulatory policies. If this continues, it will result in substantial if not gross damage to our estuarine resources.

There appears to be a general belief among the public, conservationists, and even some scientists and regulatory agencies that all wastewater treatment systems accomplish the same or similar objectives. Wastewater treatment is conceived as uniformly good, depending only upon the level or cost of treatment (i.e., the higher the cost the better); therefore, the higher the level of treatment for a given discharge location, the better the results. Unfortunately, generalizations of this type may lead to wastewater system designs that are inappropriate for the particular situation both technically and economically. In some cases, such systems could produce drastic effects on the local ecosystem.

The estuaries and coastal regions of the United States are the ultimate recipients of the major portion of conservative (non-decayable) pollutants discharged to inland lakes and rivers directly connected to the sea. In addition, a substantial additional load of both conservative and non-conservative pollutants is discharged directly to the estuaries from municipalities and industries located on the immediate estuarine periphery. Obviously, conservative pollutants as well as some of the non-conservative (decayable) pollutants will reach the coastal area in a relatively short time. Considering the estuary's location in the wastewater recipient-transport structure, in the interest of long-term protection of the estuarine system, it would appear prudent to reduce the locally generated waste load as much as is economically feasible by either wastewater treatment or removal from the estuarine system.

Unfortunately, the subject of estuarine and coastal wastewater disposal has not received as much attention as that of inland disposal practices. Consequently, the advantages and disadvantages of traditional inland wastewater treatment and disposal applied to the estuarine/marine systems have not been elucidated clearly. Of the total effort expended on estuarine problems, most has been devoted to studying the physical-hydraulic/exchange aspects of the problem, rather than the biological and chemical effects on the local ecosystem.

THE PROBLEM—WHAT AND WHERE TO DISCHARGE?

The nature of the estuarine wastewater management problem depends upon the regulatory agency position, the characteristics of wastewater discharges, and of the estuary itself, and the particular beneficial uses that are to be protected. Regulatory requirements always affect wastewater management; however, in the estuarine system these may play a special role in eliminating treatment-disposal options that may have both economic and ecological benefits. For example, if the minimum degree of wastewater treatment required, regardless of location of the discharge, is secondary treatment (such as current federal policy), then the option of using the incremental cost between primary and secondary treatment to transport the waste water to the open coast for submarine outfall-diffuser discharge (following primary treatment) is not available.

Problem Types

The types of estuarine pollution problems encountered range from those found in inland lakes and rivers to those that may be associated with nearshore, shallow, coastal waters. The geometry and characteristics of the estuarine system and the wastewater discharge will determine the type of pollution problem. In estuarine systems as elsewhere, the effects of pollutants can be highly variable; nonetheless, they can be lumped into several general categories that describe roughly the general spectrum of problems and effects.

Microbial/Public Health

One of the oldest parameters of wastewater pollutants is the coliform group of bacteria. These organisms are used as presumptive indicators of the presence of pathogens. Concentration levels of coliform organisms (MPN/100 ml—most probable number of coliform bacteria) are established to protect the waters for water contact sports, shellfish growing and harvesting, aesthetic enjoyment, and so forth.

Organic Enrichment/Oxygen Depletion

The classic oxygen demand parameter of wastewaters is its biochemical oxygen demand (BOD), the removal of which has been the principal objective of secondary treatment processes. The addition of organic matter or BOD exceeding the natural capability of respiration, synthesis, and reaeration processes (assimilative capacity) of the receiving waters may result in substantial depletion of the dissolved oxygen content of the water. Such depletion may adversely affect its suitability for maintaining a balanced biota, sport or game fish having some of the highest dissolved oxygen requirements.

Suspended Solids/Water Clarity

The second major municipal wastewater constituent that is removed in substantial degree (65–90 percent) by primary and secondary wastewater treatment processes is that of suspended solids. However, in most estuarine systems the amount of suspended solids contributed by wastewater discharges is a very small fraction (<1.0 percent) of the total suspended solids contributed by river inflow, surface runoff and resuspension of bottom sediments. Similar, but somewhat less extreme relationships exist for the organic (volatile) fraction of the suspended solids.

Acute Toxicity/Biotic Stress

A relatively new "lumper" parameter of the acutely toxic substances (toxic metals, organics, ammonia, et cetera) present in wastewaters, the fish bioassay for determination of the median tolerance limit (TL_{50}) is being used to an increasing degree in assessing potential toxic stresses from wastewater discharges. One of the major concerns about adverse stresses on the biota of estuarine systems is that of acute toxicity and increasingly stringent requirements are being imposed both on the concentration in the wastewater discharges and in the receiving waters.[1,2,3]

Floatables/Aesthetic Enjoyment

The amount of particulates of identifiable wastewater origin and slick forming materials (oil and grease) constitute one of the most significant characteristics of public wastewater discharges for which there is no adequate quantitative method for assessment. Nonetheless, in terms of potential adverse and obvious effects on the receiving waters, these materials must be given increasing attention. Fortunately, the oil and grease fraction of the floatables can be quantitated crudely, and control levels established to minimize the physical appearance of surface films or slicks.

NUTRIENTS/EXCESSIVE ENRICHMENT

Quantitation and control of the discharge of the various nutrient forms, nitrogen, phosphorus and others, is possible in those estuarine situations where adequate information is available to show that specific nutrient species are in fact, controlling the level of phytoplankton in the receiving waters. Unfortunately, adequate information is rarely available to show clearly that a particular nutrient (or several nutrient species) is actually responsible for the existence of excessive plankton concentrations or excessive pulses (blooms) in the concentration of particular algal species. Generally, practical control of the discharge of particular nutrients is based upon the presumption that it will help to keep the concentration of plankton in the receiving waters within acceptable limits.

EXOTIC POLLUTANTS/SPECIAL EFFECTS

On occasion, exotic or special pollutants may give rise to unusual problems which fall in a separate category. An example might be that of identifiable chlorinated hydrocarbon compounds in public wastewater systems.[4] Such problems may require special methods for their solution ranging from extensive source control efforts[5] to the application of special treatment systems.

Treatment/Discharge Location Considerations

INSTITUTIONAL/REGIONAL

Most estuaries have a substantial number of discrete public (municipal) and private (industrial) wastewater management organizations located around their periphery. The number and type of these organizations depends upon the historical development of the area as well as upon local wastewater regulatory policies and practices. For example, in the San Francisco Bay area there are currently (1974) over 100 different political or administrative institutions, each involved with its own particular wastewater management problem. It should be obvious that the development of a coordinated or regional wastewater management program will require a tremendous effort to satisfy the legitimate technical, economic and political interests of each organization. Nonetheless, the development of a coordinated and appropriate regional wastewater management plan is essential for the prime reason of economy, to say nothing of ancillary benefits, not the least of which is adequate protection of the local ecosystem.

HOW MUCH TREATMENT AND WHY?

The critical problem in estuarine waste management after resolution of the political-institutional problem, is what level of wastewater treatment is required and where should the treated effluent be discharged? Historically, the general trend in wastewater management has been to invest heavily in treatment processes—frequently as much as can be financed, and to pay little attention to the location and type of dispersal system. This general and significant neglect has been and still is being abetted by those who believe that the diluting or assimilating characteristics of the receiving water should not be considered in the design process. Regardless of one's philosophy on this question, the hard facts are that the treated effluent must be discharged to and diluted with the receiving water. The faster that this dilution can be accomplished, or the greater the immediate dilution of the effluent with the receiving water the lower the concentration of pollutants in the receiving water environment. Consequently, for any level of pollutants in the treated effluent, the greater the dilution the lower the concentration, and the effect on the local ecosystem is reduced proportionately.

In the past, the choice of the level of wastewater treatment has been somewhat arbitrarily made between the minimal, or primary (mechanical removal of suspended and settleable solids) and secondary (biological) treatment. However, with the advent of PL 62-500 and EPA's definition of the minimum acceptable wastewater treatment regardless of location as secondary,[6] the apparent treatment choices will be between secondary and advanced waste treatment (tertiary). Thus the fundamental question remains, is it preferable to provide advanced waste treatment and discharge the highly treated effluent directly to the estuary with little or no concern for the discharge location or initial dilution; or, is it preferable to employ a lesser degree of treatment (i.e., secondary which is cheaper with lower levels of pollutant removal), and transport the effluent to a distant area, such as the open coast, where high dilutions (at least 100 to 1) are available. The latter, equal-cost alternative, would use the incremental cost between advanced and secondary treatment to transport the effluent seaward, preferably to the open coast, where greater volumes of diluting water are available.

Unfortunately, an attitude appears to be developing in favor of continuously increasing the degree (and cost) of wastewater treatment with least consideration to the location of the ultimate discharge, the degree of initial and subsequent dilution of the waste water, or to the decay rate of the pollutants

in the receiving water. This trend appears to be supported by many of the consulting engineers and scientists involved with the design of wastewater management systems. If the foregoing concept becomes accepted and practiced widely, it will discourage any economic or ecologic incentive to use the incremental cost between various levels of treatment to transport the lesser treated effluent to a disposal site with maximum diluting capabilities and the least adverse effect on the local ecology.

If one is concerned about pollutant concentrations in the environment and their effects, one must give serious consideration to determining waste discharge locations where the residual pollutant concentration will have minimal ecological (including human) impact. To accomplish this, it should be obvious that quantitative information must be available on pollutant mass emission rates and concentrations, on the efficacy of pollutant removal processes, and on the physical, chemical, and biological characteristics of alternative disposal sites. The practical facts are that such information is not generally available to permit rational assessment of alternative treatment and dilution combinations. However, this lack of such information in no way justifies the absence of rational qualitative assessment of the consequences and quantitative assessment of the costs of the various alternatives.

DILUTION REALITIES

The available dilution of wastewaters within an estuary depends upon the size of the estuary, the amount of advective (river) inflow, tidal exchange, the quantity of wastewater, and the discharge location. For most estuaries located in urbanized areas, the available dilution ranges from approximately the ratio of river inflow to wastewater flow at the head end of the estuary, to a maximum of from 30-50 to 1 for a well designed diffuser discharge at the seaward end of the estuary. Obviously, these numbers will vary depending upon runoff, river flow, tidal exchange, and waste flow. However, in general, the available dilution for wastewaters discharged within the estuarine systems is markedly less than is often implied. For example, if all estimated 1,990 municipal and industrial wastewaters generated around the periphery of San Francisco Bay were collected and discharged to the central bay in front of the Golden Gate, the average dilution of the wastewaters would be in the order of only 30 to 40:1. And, it must be noted that San Francisco Bay is a large estuary with appreciable river inflow and tidal exchange.

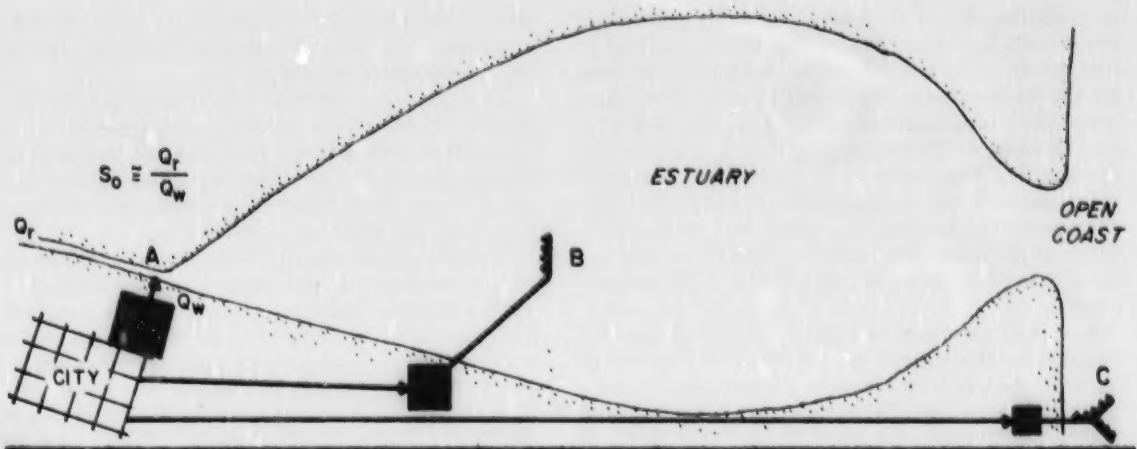
In contrast, wastewater disposal systems located along open coasts (such as the California coast adjacent to San Francisco Bay) can be designed to achieve immediate dilutions of the wastewater with ocean water in the order of 150:1 or more for waste flows up to at least 1.5×10^6 m³/day (~400 mgd). While these dilutions may appear to be on the favorable side, it is difficult to envision any likely disposal area along the major U.S. coastlines where well-designed submarine outfalls could not achieve average initial dilutions of 100:1 or more.

It is helpful to put the effect of treatment or pollutant removal in terms of equivalent dilution; that is, the reduction of pollutant concentrations in the effluent stream. Conventional secondary treatment plants affect, as an average, about 90 percent of the pollutants for which they are designed (essentially BOD and suspended solids). Thus, about 10 percent remains as residual pollutant concentration in the effluent. Such treatment efficiency is equivalent to a dilution of ~10:1, if the diluting water has negligible concentrations of that pollutant. Similarly, advanced waste treatment processes may achieve at best an average removal of about 98 percent, leaving about 2 percent of the original pollutant in the effluent. This is equivalent, on a pollutant concentration basis, of an average dilution of only 50, assuming of course that the dilution water is essentially free of the pollutant.

The foregoing examples do not consider the efficiency of disinfection processes for bacterial removal. Disinfection efficiency is a combined function of disinfectant dosage and contact time and to be effective must achieve levels equal to or greater than, 99.99 percent removal which is equivalent to a physical dilution of about 10,000:1 with bacteria free water. Obviously, the latter physical dilution is not a likely possibility.

Example of Alternative Analysis

To illustrate most effectively some of the logical treatment/transport-discharge alternatives that should be considered in designing estuarine waste management systems, a simplified example will be considered. Figure 1 shows a typical estuary connected to the open coast with a major city located at its head. The city has several obvious choices with respect to the disposal of its wastewater. One choice, designated as discharge location A, would entail a high degree of treatment—say advanced waste treatment (average of 98 percent pollutant removal)—to meet discharge or effluent requirements. A second alternative, designated as discharge location B, would entail modified secondary treatment with an average pollutant removal of about



1	DISCHARGE LOCATION	A	B	C
2	INITIAL WASTE DILUTION, S_o (MIN. RIVER FLOW)	10	30	150
3	POLLUTANT CONCENTRATION NEAR SOURCE (AT DIFFUSER) (NO TREATMENT)	$\sim \frac{C_o}{10}$	$\sim \frac{C_o}{30}$	$\sim \frac{C_o}{150}$
4	TREATMENT (ASSUME) PERCENT REMOVAL OF POLLUTANT	98	90	85
5	POLLUTANT CONCENTRATION NEAR SOURCE IN RECEIVING WATER	$\sim \frac{C_o}{500}$	$\sim \frac{C_o}{300}$	$\sim \frac{C_o}{1000}$

FIGURE 1.—Idealized estuarine-coastal disposal alternatives.

90 percent. The third alternative discharge, location C, would have the current EPA minimum secondary treatment with an average of 85 percent removal of pollutants. Alternatives B and C obviously entail significant transport and submarine outfall dispersion systems compared to that required at discharge location A. To make these alternatives economically competitive, the incremental cost between the levels of treatment required at the B and C locations and that required at location A will finance construction and operation of the interceptor sewer and submarine outfall diffuser system on a break-even basis.

The basic questions to be answered are:

1. What are the average residual pollutant concentrations in the receiving waters right at the discharge location? Presumably, from an environmental point of view, the system producing the lowest pollutant concentration in the receiving waters would be the preferred solution.

2. On an equal cost basis, how long an interceptor sewer and submarine outfall can be built for discharge locations B and C with the incremental savings in treatment costs ($A > $B > $C)?

3. What advantages may be associated with each alternative?

POLLUTANT CONCENTRATIONS

To answer the first question outlined above, a simple tabular computation analysis is presented in Figure 1. While the dilution values reported in Figure 1 are hypothetical, nonetheless, the values are typical of those found in real estuaries. Obviously, these values must be estimated for each particular estuary. The crux of the analysis is to illustrate the need to compare the trade-off in costs and consequences of pollutant removal with transport and disposal in areas of high dilution potential--with the goal of achieving reduced levels of pollutant concentrations and effects in the estuary.

Line 2 in the table shows the average physical dilution of the wastewater with the receiving water at each of the three discharge locations. At location

A, a dilution, So, of 10:1 assumed, that is, the ratio of the river flow Q and wastewater flow, Q_w (Qr/Qw) is about 10:1. At point A the only dilution available for the wastewater is the advective river flow: there is no dilution at the head end of the estuary due to tidal exchange. At location B, line 2, the average dilution, So, is assumed to be about 30:1, a typical value encountered in estuaries. At location C, the average initial dilution, So, is assumed to be 150:1 which is an easily attainable value with a well designed outfall-dispersion system in open coastal waters.

Line 3 in the table reports the pollutant concentrations in the mixed wastewater-receiving water right at the discharge location. The pollutant concentration is simply the reciprocal of the dilution; that is Co/10 at A, Co/30 at B, and Co/150 at C, where Co is the pollutant concentration in the untreated waste water. This computation assumes that the pollutant concentration in the diluting water is negligible.

Line 4 introduces the effect of the different treatment levels in reducing the pollutant concentration in the discharged waste and correspondingly in the receiving water. As mentioned previously, it is assumed that the highest level of treatment is provided at location A with an average pollutant removal efficiency of 98 percent. A lower degree of treatment with an average pollutant removal of 90 percent is provided for location B. At location C a still lower level of treatment is provided; however, this is assumed to be equivalent to the "EPA defined secondary treatment," the currently specified minimum level of acceptable treatment, providing an average of 85 percent removal of pollutants.

Line 5, the crux of the table, shows the calculated concentration of pollutants in the receiving water resulting from the combined effect of pollutant removal by treatment and the dilution of the treated effluent with the receiving water. The pollutant concentration at location A of Co/500 is the result of the product of the physical dilution, So, of 10:1 and the equivalent dilution of 50:1 due to the pollutant removal (98 percent) by treatment (2 percent remaining), which gives $Co/10 \times 1/50 = Co/500$. The values of Co/300 at B and Co/1000 at location C are found in the same way.

It should be noted that alternate C, the coastal outfall discharge, produces a pollutant concentration at the diffuser equal to one-half (Co/1000 vs Co/500) that produced by alternate A, advanced wastewater treatment with discharge at the head of the estuary. Thus, discharge at point C should be the preferred solution to minimize ecological effects. The reported concentrations relate to all pollutants that are removed by treatment at the percentages cited for each level of treatment, namely, 98, 90, and 85 percent respectively.

Two questions logically might be asked concerning the efficacy of the several alternatives.

1. Which alternative is preferred relative to possible effects of pollutants that are either unknown or are removed to a lesser degree than the pollutant removals stated for each process?

2. Although alternate C apparently produces the lowest pollutant concentration, it also has the highest pollutant mass emission rate to the environment. If the pollutants are concentrated or magnified in the biota, will not alternate C be the poorest solution rather than the preferred solution?

Both of the foregoing questions need serious consideration. With respect to question 1, and considering our imperfect knowledge about pollutants and their effects, one should be concerned about both possibilities. Inspection of the table in Figure 1 reveals that in both cases, alternate C is the preferred solution, because the total apparent dilution is less dependent on the "equivalent treatment dilution" and depends in major degree on the physical dilution to produce the lowest pollutant concentrations. For example, if all treatment processes failed or suffered serious loss in removal efficiency, such as has been known to happen, alternate C would produce a pollutant concentration in the receiving water of Co/150 compared to Co/10 for alternate A—more than a order of magnitude lower pollutant concentration which is not insignificant in terms of possible effects on the local ecosystem. Moreover, in an era of labor strikes and chemical shortages, the possibility of major impact on process performance from this standpoint alone must be considered.

With reference to question 2, it must be remembered that pollutant effects are a function of both the pollutant mass emission rate (i.e., kgms/day), and pollutant concentration for a given exposure or contact time. However, the direct effect of pollutants on any aspect of the environment is primarily concentration dependent for a given exposure time. This is true for both conservative and non-conservative pollutants, including those materials that may be concentrated (magnified) in the biota. The rate at which any effect is demonstrated by any transport mechanism known to the writer is concentration dependent; that is, the higher the pollutant concentration the more rapid its accumulation or effect on the biological system. Consequently, any wastewater management system that produces the lowest pollutant concentration in the environment at the discharge point will have the least effect on the local ecosystem.

No mention has been made of the effect of pollutant decay rates on the preferred discharge location. For pollutants such as BOD where a significant decay rate exists, it should be obvious that for the "within the estuary" discharge locations (A and B), oxygen demand will be exerted and in some cases may impose significant oxygen depression in at least part of the estuary. Thus, some of the estuary's pollution assimilative capacity will be utilized. However, for the discharge location on the open coast, C, the oxygen demand imposed with an initial dilution of 150:1 is generally non-detectable in terms of the dissolved oxygen level of the coastal water.

Several other significant advantages are associated with coastal wastewater discharge, alternative C. First, by removing the locally generated wastewater load from the estuary, one preserves the capacity of the estuary to handle the ever increasing quantity of pollutants generated upstream in the drainage basins tributary to the estuary. These pollutants are included in the incoming river flow and there are no economically feasible methods for their removal once they reach the head of the estuary. Second, it is likely that the coastal region will have an area available for wastewater discharge that will be less important and sensitive from the standpoint of the local ecosystem than the estuarine region. Third, some nutrients such as nitrogen may need to be removed from the wastewater discharge to control excessive enrichment of the estuary. Coastal waters are generally deficient in nutrients, nitrogen in particular, so there would be no reason for their removal. In fact, the nitrogen sources may be valuable for the controlled enrichment of coastal waters. This is a practical example of a pollutant in one situation which might become a valuable resource at another location.

TREATMENT/TRANSPORT—DISPOSAL TRADE-OFFS

To answer question 2, how large a transport/disposal system can be constructed and operated for the incremental cost between the alternative plans, it is necessary to deal specifically with the cost functions for treatment, interceptor and outfall sewer construction. It should be obvious that the incremental cost saving between two levels of treatment can be considered as available for wastewater transport (interceptor sewer) and submarine outfall/diffuser construction and operation. Thus, we can compare one system with a high level of treatment and discharge with minimal dilution close to the source of waste generation, to an alternate system with a lower level of treatment (also lower cost) but transport and disposal to an area of high dilution capability. Obviously, a rational comparison of alternatives entails quantitative comparison of both sites with respect to dilution capabilities and ecological characteristics.

It must be recognized that a rational comparison of alternative treatment levels and disposal sites unfortunately is not often made. We simply lack definitive environmental data on dilution capabilities and ecological characteristics of the alternative disposal sites, as well as on pollutant parameters and treatment process removal characteristics. The latter is especially true for the evolving pollutant parameters such as floatables, acute toxicity, and enrichment. However, the lack of this data should not preclude the simple economic comparison of treatment-transport alternatives, an example of which follows. To evaluate properly the role and economic justification of the optimum combination of wastewater treatment-transport, and the appropriate dilution-dispersion system, it is necessary first to consider the current unit costs of each component.

TREATMENT

Table 1 presents a summary tabulation of the 1973 California total unit costs for several levels of treatment and four sizes of treatment plants ranging from a capacity of 1 million gallons per day (1 mgd) or the flow from about 10,000 persons, to a 1,000 mgd plant which would handle the wastewater flows from about 10 million persons. The unit costs are ex-

Table 1.—Estimated 1973 unit costs* of wastewater treatment *Capital, operation and maintenance in $/million gallons ($/mg)

Treatment system	Plant design flow			
	1 mgd 3,780 m³/day	10 mgd 37,800 m³/day	100 mgd 378,000 m³/day	1000 mgd 3.78×10^6 m³/day
Primary	280	125	70	55
Intermediate (Chemical, filtration, chlorination)	490	280	140	100
Secondary (Act. Sludge, filtration, chlorination)	490	280	140	100
Advanced				
a) (Chemical, filtration, act. carbon chlorination)	910	430	245	175
b) (Act. Sludge, chemical, filtration, act. carbon, chlorination)	980	475	265	200

* Costs: a) Include disposal of waste residuals.
b) Treatment capital costs based upon 20 year life, i = 5%.

pressed in dollars per million gallons ($/mg) and include all costs: capital (based upon 20 year life and 5 percent interest), operation, and maintenance.

TRANSPORT

The cost of the transport system, principally that of the interceptor sewer depends primarily upon the surface and subsurface conditions along the pipeline route. Pumping, if required to overcome the friction loss for the pipeline system, constitutes a small fraction (< 10–15 percent) of the total cost for a system of reasonable size (10 to 200 mgd). Table 2 presents estimated 1973 California construction costs for dry-trench construction of interceptor sewers of suitable size to handle the three example flow rates considered.

OUTFALL

The costs of submarine outfall diffuser systems vary considerably because of differences in construction (surf, et cetera) and bottom conditions. Also, the cost of the inshore-surf section is high where the outfall must be buried for protection of the pipe. The average cost of outfalls depends upon the length of the outfall and fraction of inshore to offshore lengths. For outfalls in excess of one mile in length and for construction to terminal depths of 25 to 60 meters, Table 3 presents the best estimate of 1973 construction costs based upon actual costs of outfalls constructed along the Pacific coast during the past 20 years. Essentially all of these outfalls have been designed to provide average dilutions of the waste water with the coastal waters of at least 100:1. Actual performance of the built systems generally results in average dilutions higher than the design objective.

BREAK-EVEN INTERCEPTOR-OUTFALL LENGTH

If one considers the incremental treatment cost between advanced waste treatment, alternate B (see Table 1) and secondary treatment, assuming that to be the minimum treatment level allowed, one can compute the length of interceptor or outfall that can be built for this incremental annual cost. Table 4 presents a summary computation of these pipeline lengths based upon the cost data cited in Tables 1, 2 and 3. The table shows the computed interceptor and outfall lengths that can be built for the incremental treatment costs between advanced wastewater treatment, alternate B, for three wastewater flow rates, 1 mgd, and 100 mgd.

Table 2.—Estimated 1973 unit construction costs*—interceptor sewers

Design flow		Sewer size		Construction cost	
mgd	m³/day	inches	centimeters	$/foot	$/meter
1	3,780	10	25.4	18.00	60
10	37,800	36	91.5	63.00	206
100	378,000	96	245	205.00	672

* Dry Trench Construction.
EPA Index = 200.

Table 3.—Estimated 1973 unit construction costs*—submarine outfalls

Design flow		Sewer size		Construction cost	
mgd	m³/day	Inches	Centimeters	$/Foot	$/Meter
1	3,780	6	15	100	330
10	37,800	24	61	425	1,395
100	378,000	76	194	830	2,720

* California construction practice.
EPA Index = 200.

It is of particular interest to note the considerable lengths of interceptor and outfall sewers that can be built for a wastewater flow of 100 mgd (equivalent to a city of about one million persons). About 77 miles of interceptor or about 18 miles of submarine coastal outfall can be built and operated for the incremental cost between secondary and advanced treatment, alternate B. Obviously, the total incremental treatment cost would not be used to build only interceptor sewers or submarine outfalls (unless the city was located directly on the open coast). A realistic, break-even solution would permit the construction of a 100 mgd secondary treatment plant with about 38 miles (77/2) of land interceptor and about 8 miles (17.8/2) of submarine outfall discharging at C on the open coast for the same cost as an advanced wastewater treatment plant (alternate B) discharging at location A at the head of the estuary. As noted previously, these pipeline lengths neglect the cost of pumping to overcome the friction loss during transport (i.e., assumed gravity flow). However, if such pumping were required due to the topography, it should be included in the trade-off analysis, but it would reduce the pipe lengths that can be built by less than 10 percent. Obviously, if suitable open coast disposal sites were available closer to the wastewater source (or a shorter outfall would suffice), then the coastal alternative (location C) would be more economical than treatment and discharge at location A.

The data presented in Table 4 indicate that waste-

Table 4.—Lengths of interceptor sewer or submarine outfall that can be constructed for incremental cost between secondary treatment and advanced waste treatment, alternate b†

Flow	Incremental unit cost secondary to AWT Alt.b.		Total annual incremental cost sec. vs. AWT Alt.b.	Equivalent interceptor length*			Equivalent outfall length**		
mgd	$/mg	$/m³	$	Unit cost $/Mile-yr	Miles	Km.	Unit cost $/Mile	Miles	Km.
1	490	0.13	179,000	5,230	34.2	55	30,800	5.8	9.3
10	195	0.053	712,000	18,200	39.1	63	131,000	5.4	8.7
100	125	0.033	4,560,000	59,400	76.7	124	286,000	17.8	28.6

† See Table 1 for process description.
* Based upon useful life of 50 yrs, i = 5%; Friction losses (pumping) and O&M not incl.
** Based upon useful life of 40 yrs, i = 5%; Friction losses (pumping) and O&M not incl.

waters can be transported great distances on either land or in the sea for the cost of upgrading the level of wastewater treatment. Certainly, there is adequate evidence to indicate that in planning an estuarine wastewater management system, a reasonable extensive investigation of alternative disposal sites, both within the estuary and on the open coast, is warranted before decisions are reached to provide very high degrees of wastewater treatment with disposal to the local environment. It should be noted that the preceding analysis is based upon a comparison of secondary and advanced wastewater treatment. Where regulations do not require secondary treatment as a minimum, a similar comparison can be made for the incremental cost between primary and secondary treatment. Surprisingly, the incremental cost between primary and secondary treatment is of similar magnitude as that between secondary and advanced treatment used in the example computation; hence, similar transport distances would be obtained.

Ancillary Considerations

Several additional aspects of the open coast disposal alternative should be mentioned. First, it has shown that it is economically possible to transport about 100 mgd of wastewaters over 70 miles at the same cost as upgrading treatment from secondary to advanced (or from primary to secondary treatment). From an environmental or ecological point of view, it would appear highly logical to expect that, within a distance of that magnitude from the wastewater source, one could find a wastewater discharge location with high dilution capabilities and of lower ecological significance than discharge at or near the head of an estuarine system.

Yet a valid argument can be made against coastal waste disposal. In the long term we cannot afford to waste the freshwater sewage to the sea; it should be reclaimed. In many places, such as California, this may well be true. If wastewaters are ever to be reclaimed for beneficial reuse, including public water supply, more pollutants must be disposed of than at present. Moreover, the major pollutant to be removed to permit continued reuse is salt. Where is a better sink for salt and other non-reclaimables, after suitable terminal treatment, than the sea? Nowhere in the writer's judgement—at least for those cities located in the coastal zone.

Moreover, in the short term, one of the major adjuncts for wastewater reclamation is the existence of a marine outfall not only to handle the treated non-reclaimable substances compatible with the sea, but to provide an effective, economic alternate disposal system for the wastewater when it is not possible to reclaim it all (i.e., seasonal and demand variations, failsafe provisions, and so forth).

CONCLUSIONS

Rational analysis of estuarine wastewater management requires: (1) consideration of the efficacy of several levels of treatment with respect to pollutant removals and costs; (2) the consequences and costs of transporting adequately treated wastewaters to disposal sites with high diluting capabilities and/or low levels of significance in the local ecosystem; (3) and the effects of the resulting pollutant concentrations in the receiving water environment. The absence of adequate data on pollutants, their removal or effects, or on the characteristics of the local ecosystem, should in no way preclude the straightforward comparison of alternate treatment/transport/disposal systems on an economic and pollutant concentration basis such as presented herein.

Adequate conceptual design of wastewater management systems requires consideration of the incremental costs between several possible levels of wastewater treatment for assessment of the trans-

port distances that the wastewater can be conveyed to a disposal site with high diluting capacity and/or a lesser level of significance in the local ecosystem. An example computation shows that for a 100 mgd (378,000 m^3/day) plant the incremental cost between secondary (including filtration) and advanced waste treatment, an interceptor sewer 38 miles (61 km) long and a coastal submarine outfall ~9 miles (~14 km) in length can be constructed at 1973 California prices.

As has been shown, in many situations the coastal outfall alternative not only provides the lowest waste concentrations, but also may well be the most economic. Moreover, the coastal alternative is highly superior to the high treatment-estuary disposal alternative for unknown pollutants or pollutants only partially removed by the conventional treatment processes (i.e., some toxic substances).

In general, a number of specific advantages can be claimed for open-coast, treatment-disposal alternatives as compared to higher treatment level and disposal within the estuary. These can be summarized as follows:

1. Produces the lowest concentrations of pollutants in the receiving waters for conventional levels of treatment.
2. Discharge location likely can be in area of lesser significance in the local ecosystem.
3. Reduces pollutant stresses on the estuarine ecosystem resulting from locally generated wastewater, thereby allowing capacity for the inevitable increasing pollutant stress associated with incoming river flow and drainage basin pollutant contributions.
4. Because of the high terminal dilutions, greater protection is provided for the local ecosystem from:
   a) Unknown pollutants or those not removed by treatment.
   b) Treatment process malfunction or failure (strikes, et cetera).
5. Provides maximum economy and flexibility to deal with:
   a) Identification and control of new pollutants.
   b) Major improvements in treatment technology.
   c) Future development of engineered wastewater reclamation.

In short, if long-term protection of our estuarine resources is to be provided, all technical and economically feasible steps should be taken wherever possible to transport adequately treated wastes out of the estuarine system to the open coast in well engineered, high dilution capacity outfall dispersion systems.

RECOMMENDATIONS

The federal government in cooperation with the states should sponsor large scale field investigations of all significant estuaries and adjacent coastal waters. The focus of these studies should be twofold:

1. Development of quantitative descriptions of the estuarine ecosystems to permit realistic assessment of the characteristics of the flora and fauna, its general condition or "health" and the general level of sensitivity and biological significance of the various portions of the estuary and adjacent coastal waters.
2. To identify, insofar as possible, the significant effects of pollutants on the estuarine ecosystem—at least to the degree of categorizing what appears to be the critical pollutant problems and parameters associated therewith.

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POLLUTION PROBLEMS IN THE ESTUARIES OF ALASKA

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ABSTRACT

The Alaskan marine coastal systems are classified into 13 categories which represent nearly all systems found in the 48 contiguous states with the exception of tropical systems and those heavily stressed by petrochemical and other complex industrial pollutants. Alaska is the only state that has ice-stressed coastal systems. It also has 54 percent of the United States coastline and 53 percent of its tidal shoreline.

The scope of Alaskan coastal pollution problems at present and in the future are examined. Minor problems associated with wastes from municipalities and activities of the petroleum, timber, pulp and paper, and the fishing industries are presently evident. Increased petroleum production and the associated transport of oil products through Alaskan coastal systems poses a future large scale pollution risk.

An evaluation of previous Alaskan coastal pollution abatement programs and trends is given. Because Alaska has such unique coastal systems it is concluded that any future coastal pollution control program will succeed only if based on sound environmental data rather than on adaptations of standards uniformly administered throughout the 48 contiguous states. Emphasized through the paper is the need for better environmental understanding of Alaska's coastal systems upon which decisions can be wisely made that will protect them, and at the same time utilize them for waste disposal and extraction of the resources needed to benefit man.

INTRODUCTION

Alaska, with its total population of about 350,000 people is very sparsely populated. Centered around Anchorage is a population of 150,000 which constitutes by far the largest population center; Fairbanks is second with about 40,000, and Juneau third with about 20,000. The remaining population is composed of small villages and towns, mostly located on the coast. Most of the villages are native and still adhere to native customs and practices.

Most Alaskans live on the state's coast, a coast that extends from the rain forest of southeast Alaska to the arctic tundra (Fig. 1). The gradation from temperate to arctic, which encompasses a very broad geographical range in latitude and longitude, includes all types of coastal systems found in the contiguous 48 states with the exception of tropical systems and those stressed by petrochemical and other complex industrial pollutants. Alaska is the only state that has ice-stressed coastal systems. There are four types: glacial fiords, turbid outwash fiords, sea ice systems and ice-stressed coasts. The first two types occur in southeast and southcentral Alaska and the last two types are arctic (Fig. 1 and Tables 1 and 2).

The small population of Alaska, although concentrated on the coast, has had a very limited influence on the natural systems of the 76,100 km of Alaskan tidal shoreline. But, Alaska is presently experiencing rapid economic growth primarily from development of the natural resources (e.g., petroleum, timber and fish) near its coast and certain coastal systems are therefore already stressed by man's activities.

Classification of Alaskan Marine Coastal Systems

Alaska's coastal systems are very diverse (Fig. 1, Tables 1 and 2) because its coastline extends over a very broad geographical range. The general coastline of Alaska is 10,680 km long (McRoy and Goering, 1974), 54 percent of the total (19,924 km) coastline of the United States (Pederson, 1965). The tidal shoreline, which includes islands, inlets, and all shoreline to the head of tidewater, is much longer and reflects the intricacy of coastal Alaska. This distance is estimated to be 76,100 km in Alaska and 142,610 km in the United States. Alaska, then has 53 percent of the total United States tidal shoreline. The tidal shoreline is greatest in southeast Alaska (63 percent), where the coast is a maze of fiords, islands, bays, and rocks, and is minimal in

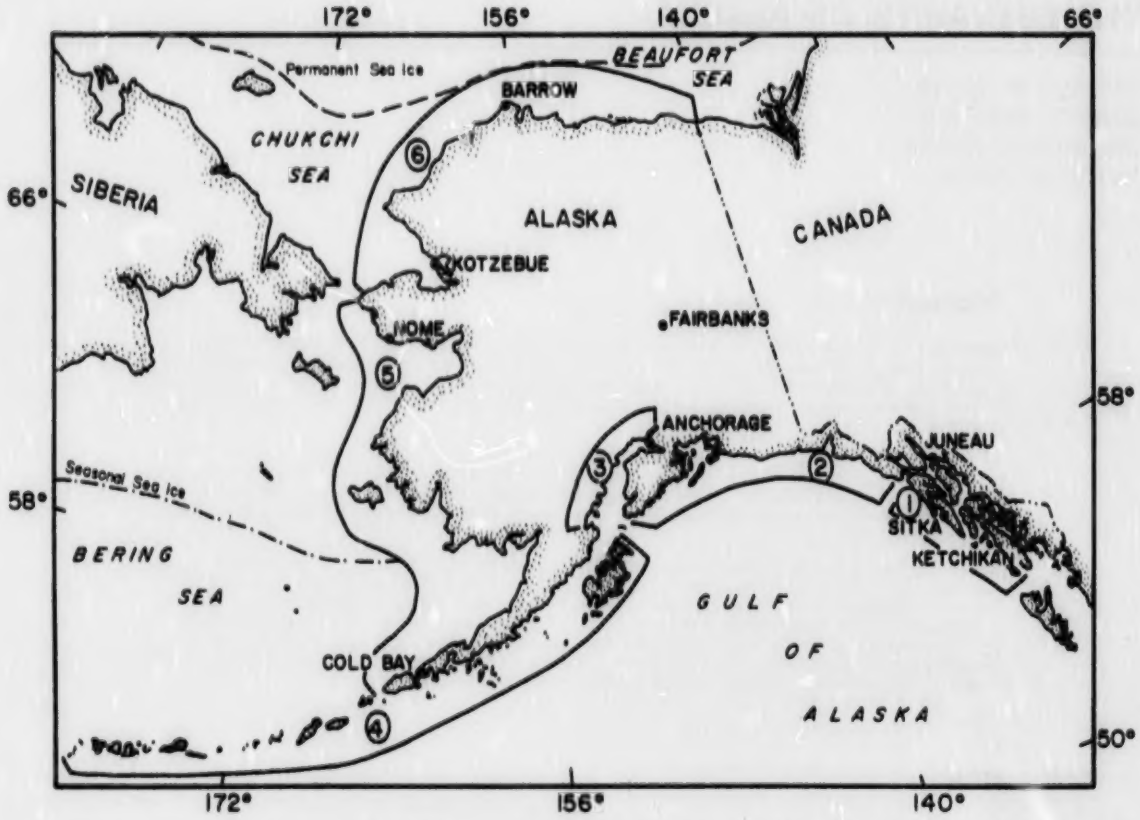

FIGURE 1.—Map of Alaska. Numerals refer to regions described in Table 2.

the arctic (2 percent), existing as a series of lagoons and barrier beaches (Table 2).

Because the four ice-stressed systems are unique to Alaska their characteristics will be briefly described.

GLACIAL AND TURBID FIORDS

The major indentations of the southeast Alaskan coastline are fiord-type estuaries. Glacial and turbid outwash fiord refers to inlets which owe their distinctive physiography to the action of glacial ice on mountainous coastal regions. These inlets are usually narrow, straight, have deep water and receive their major freshwater runoff from active glacial sources. Those fiords with active glaciers in the intertidal zone are referred to as glacial fiords. In these, most of the glacial-melt water (i.e., the major estuarine freshwater source) passes directly into the marine environment. Fiords whose glaciers terminate on land, so that the melt water reaches tide water via a freshwater river system, are termed "turbid outwash fiords." In contrast to the clear water environment of the glacial fiord, in the turbid outwash fiord large quantities of glacially-ground sediments are transported into the inlets by glacial-melt water from the sediment deposits between glacier and fiord. These sediments restrict light passage as well as influence the inlet geochemistry.

Table 1.—Types of coastal systems in Alaska

1. Glacial fiord
2. Turbid (terrestrial outwash) fiord
3. Rocky sea front and intertidal rocks
4. High velocity tidal channel
5. Neutral embayment and associated shore waters
6. Medium salinity estuary
7. Sheltered and stratified estuary
8. Oligohaline river system
9. Sedimentary river delta
10. Marshes
11. High energy beach
12. Ice-stressed beach
13. Sea ice system

Table 2.—Distribution of Alaskan coastal systems by regions (See Fig. 1)

Region	Estimated km of tidal shoreline	Percent of Alaskan shoreline	Coastal types (See table 1)
1. Southeast Alaska	48,270		68 all but 12 and 13
2. Pacific Coast, Cape Spencer to Cape Elizabeth	10,460		14 all but 12 and 13
3. Cook Inlet	800		1 4, 5 and 8
4. Kodiak Island, Alaska Peninsula and Aleutian Islands	12,070		16 3, 4, 5, 6, 7, 10 and 11
5. Bristol Bay to Bering Strait	2,900		4 3, 4, 5, 6, 7, 10, 11 and 12
6. Arctic, Bering Strait to Canadian Border	1,600		2 8, 9, 10, 11, 12 and 13

Commonly, fiords contain an entrance sill, which restricts the free exchange of waters within with those outside (Pritchard, 1952). However, all inlets in southeast Alaska do not have such sills and the amount of circulation restriction, a feature which is very important in pollutant assimilative capacity, varies from inlet to inlet. Most have entrance sill depths which allow continuous contact with the exterior source waters so that a slow circulation prevents the basin from stagnating. Where shallow sills penetrate the low salinity outflowing upper layer, exchange of deep basin water is inhibited and stagnation is theoretically possible. No fiords in southern Alaska, uninfluenced by man, show stagnation to the degree that extensive oxygen depletion occurs. The circulation in Skan Bay, Unalaska Island, one of the Aleutian Islands, however, is restricted to the extent that complete oxygen depletion occurs naturally once every year (Goering and Boisseau, personal correspondence). Stagnation as a consequence of restricted circulation also occurs in areas of limited freshwater inflow. Inflow is strongly seasonal with a pronounced primary freshwater input maximum during the period of May through July. The major energy sources within the fiords are the total freshwater inflow and the effects of tides, with the latter usually predominating.

Sea Ice System

Sea ice is a coastal system unique to Alaska. The ice itself is a type of beach with associated fauna and flora. Seals and walrus breed on the ice; diatoms and other algae grow on its undersurface; numerous species of birds feed near it; Eskimos depend on it for food and travel.

Ice is the major feature of the Arctic Ocean and northern Bering Sea in winter. Seawater in this system freezes to an average thickness of 2 to 3 m. This thickness varies locally with the severity of the winter. Losses due to surface melting are replenished by accumulation of new ice on the undersurface. The southern boundary of the sea ice varies from year to year. This limit is frequently near the Pribilof Islands (59° N., Fig. 1). The summer boundary of the polar ice is between 10 and 100 miles off the Alaskan arctic coast. During August and September the Arctic Sea adjacent to Alaska has the least ice. Advancement of the sea ice begins in late September and October but the north flowing current through Bering Strait tends to keep the southern Chukchi Sea open longer. Ice closes Bering Strait by the end of October. In late October and November Norton Sound freezes and the sea ice progresses south to its maximum in midwinter. Breakup begins in mid-April. Open water does not extend into the Chukchi Sea until June.

Ice on the sea is not one continuous mass, nor is it flat and uniform. Winds, currents, and other stresses produce openings, hummocks, and ridges in the ice. The surface topography generally reflects the undersurface topography. Polynyas and leads, a result of stresses acting on the ice, are present at all seasons.

The boundary of ice and water may take a variety of forms depending upon the given freezing and melting conditions. In the open sea, only sea ice formed by the freezing of seawater is important. However, near the coast, and in particular near river mouths, floating river ice is introduced into the oceans.

Ice-Stressed Coast

This system is characterized by ice formed by the freezing of the arctic seas. Ice along a shore has profound effects on the fauna and flora of the coast in that it eliminates most organisms from the littoral zones of the sea.

The ice-stressed littoral system reaches a maximum intensity on the northernmost coast of Alaska, from Point Barrow east, where ice is present from September through July and in extreme years may be periodically onshore all summer. The effects of ice on coastal systems diminish with the decreasing latitude along the Chukchi and Bering Sea coasts. The southern extent of the ice-stressed system varies with the intensity of winter; it can extend as far south as Izembek Lagoon near the tip of the Alaska Peninsula (55° N., Fig. 1). In these lower latitudes the ice effects are much less than in the Arctic. On the arctic coast the pressure on sea ice from wind

stress and currents is transferred to the fast ice on shore and causes scouring. Ice cover on the open Bering Sea never extends as far south as the Aleutian Islands.

Although the stress of ice influences long portions of the Alaskan shoreline (approximately 4,500 km), most studies have been limited to the region near the Naval Arctic Research Laboratory at Point Barrow. For other regions only inferences can be made based on the Point Barrow work. The best studied ice-stressed coasts are those of the arctic Soviet Union (Zenkevitch, 1963). They appear to be comparable to Alaskan coastal systems.

SCOPE OF ALASKAN COASTAL POLLUTION PROBLEMS PRESENT AND FUTURE

Alaska's extensive coastline and corresponding coastal estuarine systems are one of the state's most important resources. Estuaries are as beneficial to man as forests, lakes and rivers. They are very productive biologically as well as versatile in usefulness. A vast variety of finfish and shellfish spend all or part of their life cycle in estuaries. These serve as nurseries, as spawning and feeding grounds, and as passageways between the open sea and the spawning areas of freshwater streams. Most of the commercial seafoods harvested in Alaska are associated with coastal estuarine systems (Table 3).

These systems also provide habitat for numerous species of sea birds and marine mammals. They act as buffers against the ravages of violent storms and provide the harbors and transportation routes for commerce, and are the best potential sites for certain industrial plants. Also, Alaskan coastal waters offer a wide variety of recreational opportunities for fishermen, boaters, hunters, and wildlife observers. It is thus very clear that Alaska's coastal systems are very rich in renewable and non-renewable resources—distinctive, aquatic systems which man cannot afford to use carelessly or destructively. We must obtain a keen knowledge of how these systems function naturally before the stresses that they can accept without significant change can be assessed. Procuring information as to how these systems function naturally is the greatest challenge to wise management of their use. Without this knowledge for management decisions, failure is inevitable.

Because of the state's great diversity, baseline data on many systems is not available. Therefore, the present water quality standards which are based on the best information available, or taken from other states and areas, have many weaknesses which must be corrected as better information is obtained.

Table 3.—Alaskan commercial species of finfish and shellfish which are nurtured in estuarine environments

Group	Common name	Scientific name
1. Finfish		
Salmon	coho (silver) salmon	Oncorhynchus kisutch
	pink (humpback)	Oncorhynchus gorbuscha
	chum (dog) salmon	Oncorhynchus keta
	king (chinook) salmon	Oncorhynchus tshawytscha
	sockeye (red) salmon	Oncorhynchus nerka
Trout	rainbow trout (steelhead)	Salmo gairdneri
	arctic char (dolly varden)	Salvelinus malma
Halibut	Pacific halibut	Hippoglossus stenolepis
Herring	Pacific herring	Clupea harengus pallasi
Smelt	capelin	Mallotus villosus
Cod	ling cod	Ophiodon elongatus
Rockfish	redsnapper (yelloweye rockfish)	Sebastes ruberrimus
Whiting	shee fish	Stenodus leucichthys
2. Shellfish		
Crabs	king crab	Paralithodes camtschatica
	tanner (snow) crab	Chionoecetes bairdi
	tanner (snow) crab	Chionoecetes opilio
	dungeness crab	Cancer magister
Shrimp	pink shrimp	Pandalus borealis
	side-stripe shrimp	Pandalopis dispar
	coon-stripe shrimp	Pandalus hypsinotus
	humpback shrimp	Pandalus goniurus
	spot shrimp	Pandalus platyceros
Scallop	weathervane sea scallop	Patinopecten caurinus
Clams	razor clam	Siliqua patula
	geo-duck	Panope generosa

Environmental baseline research is the only mechanism that can supply the required information needed to upgrade and establish realistic marine water quality standards. Once realistic water quality standards are established then research to develop more appropriate methods of waste treatment and pollution abatement can begin. Without realistic standards, the government requirement for industrial and municipal installation of treatment facilities is environmentally pointless, morally irresponsible, and fiscally absurd.

Marine coastal pollution in Alaska is then caught in a dilemma. On the one hand are the extremely complex coastal ecosystems of widely diverse nature that are sufficiently different from those of other regions that the same criteria for water quality do not apply, and on the other the strong commitment on the part of the government to impose standards, usually the same as for the rest of the United States even though there is little evidence for their applicability. To exemplify this point, there seems to be very little reason to set effluent standards in Alaska

to help meet a dissolved oxygen concentration in the environment, as may be necessary elsewhere, since Alaskan waters are unusually rich in dissolved oxygen. In one test case in Silver Bay a discharge of 112 metric tons/day of 5-day BOD under less than ideal discharge conditions led to only a few violations of the state water quality standard for dissolved oxygen (6 mg/l), and this was associated with low oxygen water input resulting from coastal upwelling. It would seem advisable to put the intellectual resources available to bear on problems other than BOD discharge. Likewise, does it make sense to impose the same temperature effluent standards in Alaska; most ecosystems would benefit from higher temperatures, as in Florida or Texas where the systems are thermally stressed under natural conditions.

To protect Alaska's renewable resources it will be necessary to develop environmental standards especially directed toward local situations. In such considerations full regard to the investigation of the ocean's capacity for waste assimilation and dispersion should be given while being explicit about the nature of the waste discharged and its effects on the dominant ecosystems present.

The future marine pollution problems in Alaska will be well managed, poorly managed, or managed not at all, depending on how well the responsibilities of the oceanographic scientific community are carried out in the next few years and what kind of management plan is developed. There will unquestionably be large offshore oil developments on the continental shelves of the Gulf of Alaska, Beaufort Sea offshore of the Prudhoe oil field, the Chukchi Sea, Norton Sound, Bristol Bay, North Pacific south of the Alaska Peninsula, and the Bering Sea. These continental shelves represent 74 percent of the U.S. total. With these developments must come a proliferation of docks, harbors and transportation corridors to move the product to market. Much of the gas will be liquified before transport out of Alaska thus providing enormous quantities of heat, which under proper institutional arrangements, can probably be economically utilized to enhance renewable resource production.

Some plants will be built to utilize oil and gas within Alaska, particularly nitrogen based fertilizer plants and some types of petrochemical plants.

Alaska is an underdeveloped mineral rich resource area. Large reserves of copper, tin, molybdenum, platinum, iron, antimony and coal are yet undeveloped. Only gold and some copper has been processed until now, largely because of lack of transportation and the world economic picture. Soon this will change with the imminent world need for these raw materials. The metal beneficiation mills that will result will bring new sets of pollution problems to the state.

The timber stands in Alaska are about the same as Washington, Oregon, and Idaho combined, yet the harvest is small compared to these three states. With the shortages in wood and wood products now facing the nation and the world a greater harvest of this raw material in Alaska is inevitable. With the increased harvest will come numerous new paper, wood pulp, and wood mills with their associated pollution problems. In addition, the increased cutting will affect water quality, land erosion, and stream habitation.

Marine food production, historically Alaska's most important product, will continue to expand and Alaska will long remain as one of the world's greatest fisheries' centers. Pending the adoption of the 200-mile economic zone or some similar coastal state jurisdictional arrangement, the continental shelf of the Bering Sea, perhaps the most valuable fishery in the world, will fall under Alaska's jurisdiction. In addition, aquaculture should thrive in Alaska, especially in the coastal fiords which offer promising opportunities for marine food production without expenditure of conventional energy.

For Alaska to be a supplier of marine foods and at the same time of such materials as petroleum, lumber and associated products, places an extremely heavy burden on those investigating environmental effects to determine what stress the system can take without significant damage, and provide for means to control those stresses found to be incompatible with desirable uses of the marine environment. Government, science, and private enterprise must face these problems together realistically and with forthright determination to make this possible.

ALASKAN COASTAL POLLUTION BY TYPES OF EFFLUENTS

Petroleum Industry

Significant pollution of Alaska's coastal systems by oil has not yet occurred. Pollution by oil could, however, become a problem as soon as large amounts of it are tankered from Alaska to other areas. This is slated to begin after completion of the Trans-Alaska pipeline, about three years from now. When oil is handled, there is a spill risk, even under the best control and intentions. We must develop a data bank of its effects so that cleanup and control may be systematic and effective.

In the development of the vast petroleum reserves located in the state the danger of oil pollution must

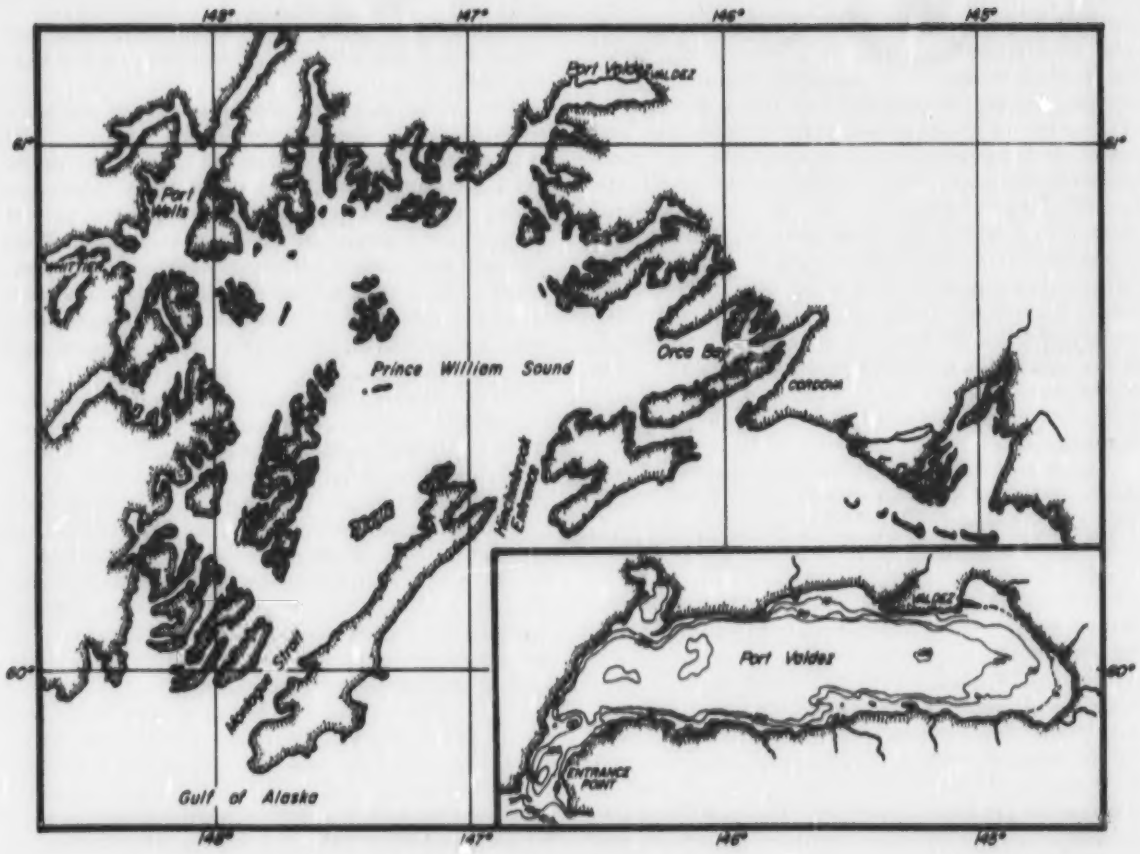

FIGURE 2.—Prince William Sound.

be foreseen and forestalled. The most immediate problems appear to surround the 800-mile Trans-Alaska pipeline which is to bring oil from the oil-rich North Slope to the ice-free tanker terminal in Port Valdez in southcentral Alaska. The coastal systems in region 2 (Fig. 1) are particularly vulnerable, especially Port Valdez, Valdez Arm, and other systems located in Prince William Sound (Fig. 2).

Prince William Sound is one of the largest tidal estuarine systems on the North American continent not yet influenced by urban development. It is comparable in size to Puget Sound yet has only a permanent population of about 5,000. The sound is an area of rich biological resources and scenic splendor. Important runs of silver, pink, and chum salmon enter the sound each summer to spawn in its numerous freshwater systems. Large stocks of king and dungeness crabs, a variety of clams and scallops, as well as commercially important pelagic fish reside there. Large numbers of marine mammals and sea birds are associated with the rich marine fauna.

When the Trans-Alaska pipeline is completed the tanker traffic in Prince William Sound and along the southeast Alaska coast will almost certainly lead to sporadic oil pollution. Chief risk areas are near the loading terminal in Port Valdez; but with sensible organization for treating them, such oil spills as occur need not cause environmental degradation.

Oil tankers returning from the west coast under ballast to load at Port Valdez will not be able to discharge dirty ballast water at sea. They will unload it into a ballast treatment plant where the oil content will be reduced to less than 8 ppm before release into the port. Thus Port Valdez will suffer planned chronic poliution of a low level. The Alyeska Pipeline Company, responsible for operation of the pipeline and terminal, commissioned a study of the hydrography, geology, and biology of

the port by the Institute of Marine Science of the University of Alaska to predict the impact of this chronic pollution. The report (Hood et al., 1973) provides information which has been used in the design of the treatment plant and effluent dispersion system to minimize the impact of this oil on Port Valdez waters. The extreme care used to investigate the pollution impact that the treatment plant might have, and to design the outfall in such a way to minimize effects, should be a model for all future industrial and urban developments in the sound.

A study to quantitatively define the magnitude of oil pollution in Alaska's Cook Inlet has been described by Kinney et al., (1969). Physical dissipation and biodegradation rates were determined and combined with estimates of hydrocarbon input rates to assess the extent of oil pollution in the inlet.

The authors report that as of the date of their report, accidental spills and effluents contribute from 10,000 to 17,000 barrels of oil per year or about 0.03 percent of the total produced and handled. The most recent spill and discharge analyses show that the 0.03 percent figure is now about 0.01 percent and will further decline as NPDES discharge permits go into effect between 1975 and 1977. When oil is added to the surface the slick is dissipated rapidly by the inlet's large tidal turbulence. This turbulence and its geometry also tend to keep spilled oil out in the inlet away from beaches, with the exception of Kalgin Island. Tidal and river-driven flushing reduces components in the inlet by 90 percent in about 10 months. Evaporation effectively removes hydrocarbon components smaller than C_{12} within eight hours and the amounts of $C_{10} - C_{25}$ hydrocarbons in Cook Inlet waters and sediments are below 0.02 μg/liter.

A microflora of hydrocarbon oxidizing organisms (about 10^3/liter) exists and functions as an inoculum and suggests the persistence of transient, possibly naturally occurring, hydrocarbons. Biodegradation of oil in the inlet is complete in one to two months. Thus biodegradation is more important than physical flushing in removing hydrocarbon pollutants from this body of water.

Many questions concerning the influence of oil on marine biota remain unanswered. The lack of this information generally results in panic when oil is spilled, although oil seeps occur naturally in coastal waters of Alaska, particularly in southeast Alaska near Yakataga, Malaspina, Icy Bay, and Yakutat (Rosenberg, 1972). The fate of oil once it reaches Alaska's coastal system needs to be assessed. Biodegradation will occur; but just how fast in the various systems isn't precisely known. Interaction of oil with silt and glacial silt will occur, but where does the silt deposit, what effects do oil-laden silt have on the benthic community and what rates of degradation may be expected? Arbitrary controls of oil pollution other than cleanup of spills should not be attempted without more knowledge of the fate and effect of oil on the marine ecosystems involved. Caution should be used when chemicals are used to clean up oil because they may, in cold water, as has been often found in warmer waters, have more detrimental effects to marine organisms than allowing natural processes to degrade the oil left after physical cleanup. It is obvious that the State of Alaska and the U.S. Government must obtain detailed knowledge of the interaction of oil and the marine environment under Alaskan conditions to avoid panic and tragedy in the event of major accidental oil pollution incidents.

Timber Industry

Among Alaska's most important industries now and in the future are those involved with forest harvest and processing. Approximately 60 individual logging companies operate within southeast Alaska (State of Alaska, 1971). They supply timber to two large pulp mills and about 20 smaller saw mills. In 1970, they harvested 560 million board feet of timber, most of which was hemlock (*Tsuga heterophylla*). Much of this timber was taken from Baranof, Kruzof, and Prince of Wales Islands. About 2.6 square km of water was used for handling and storing logs. Since some of the logging companies move their cutting sites each year, a large area of water has been used for log handling and storage in southeast Alaska. Coastal pollution problems originating from the timber industry are already apparent in southeast Alaska. Logging practices have influenced the water resources, particularly small streams in the logging areas and estuaries utilized for log storage in log rafts. The absence of roads and the distance between logging areas and processing mills have resulted in the extensive use of salt water for storage and transportation of logs. Wood-boring organisms, such as teredos, inhabit southeast Alaskan marine waters, so logs are generally stored in intertidal areas of shallow bays. These areas are chosen for extended log storage because grounding at low tide and the relatively low salinities minimize infestation by wood-boring organisms. Protection from strong winds is another factor considered when choosing storage areas.

During the log dumping and rafting processes, bark is knocked off the logs and sinks to the bottom,

often in substantial amounts. This accumulation can greatly increase oxygen demand, resulting in the depletion of benthic organisms, and also can cover the bottom to the extent that repopulation by benthic forms is prevented (Pease, 1974). Organic compounds leached from logs when stored in water, in addition to exerting an oxygen demand, add color-producing substances to the water, and some leachates (e.g. Douglas fir leachates) are acutely toxic to marine and freshwater fish (Schaumburg, 1973). Steel bands and cables which are used in the rafting process also often accumulate on the bottom.

The exact effects of water-based log handling in southeast Alaska need to be better assessed before restrictions or alternative methods of storage are imposed. In general, any method which reduces the accumulation of debris and log leachates in the shallow storage areas would appear to be beneficial.

Pulp and Paper Industry

The processing of timber by pulp mills has also seriously affected water quality in certain southeast Alaskan bays. A rather serious degradation of water quality due to inadequately treated wastes from pulp mills in Ward Cove and Silver Bay has been documented by the Federal Water Quality Administration (1970). The Alaska Lumber and Pulp Company located in Silver Bay and the Ketchikan Pulp Company in Ward Cove both operate magnesium based sulphite process pulp mills which produce a dissolving pulp for the rayon industry. Both plants have relied upon chemical recovery and screening to remove wastes and both discharge into the marine environment from outfalls without the benefit of dispersers. This treatment has been shown to be insufficient to comply with Federal or Alaska Water Quality Standards. Sulphite waste liquor concentrations known to exceed the level toxic to phytoplankton and salmon food organisms have been found throughout Ward Cove and Silver Bay. The waste liquor discharges containing a high 5-day BOD coupled with the release of solid materials, plus the inability of the waters in these systems to effectively disperse the pollutants, combine to reduce the dissolved oxygen at some times during the year. In the summer, coastal upwelling occurs, resulting in low oxygen containing waters being transported into the inlets. This event, coupled with oxygen depletion resulting from the waste load, causes the dissolved oxygen to fall below 6 mg/liter, the minimum level allowed by the Alaska Water Quality Standards. The permit requirements now being imposed are based on a discharge level for 5-day BOD per ton of product produced with no regard for environmental effects. It is not clear at this time, in the case of the Alaska Pulp Mill at Silver Bay, whether reduction of the 5-day BOD discharge level to the proposed best practical level will effectively improve the dissolved oxygen situation in Silver Bay, since it appears that the largest contributor to the low oxygen values is natural circulation and similar processes dominating this system. More consideration needs to be given to other components of the waste, and their distribution in the bay, to provide a sound environmental disposal system.

Fishing Industry

Alaska ranks as one of the leading states in the tonnage of seafood landed and processed (fourth in 1972, U.S. Dept. of Commerce, 1973). In 1972 there were 131 salmon, 72 shellfish and 50 miscellaneous fish processing plants operating along the coast of Alaska. The wastes from this industry have already brought on serious degradation of water quality and impeded the various other important and economic uses of that water. The main areas of environmental degradation are in regions where several processors are concentrated, where currents carry wastes onshore, or where water circulation is restricted and stagnation ensues.

A large percentage of the shellfish and finfish processing in Alaska is done at Kodiak. In 1972, 113,268,000 pounds of fish were landed there; only six other U.S. fishing ports had larger landings. In Kodiak, the shrimp and crab industries are faced with a complex problem. The wastes which are left after the extraction of meat for freezing or canning, the majority of the body weight (mainly entrails and chitinous skeletons), always have been dumped into Chiniak Bay beside the processing plants. This practice has created serious environmental problems, e.g., accumulation of organic debris resulting in near bottom anoxia, release of toxic hydrogen sulphide from anoxic sediments, and elevated concentrations of potentially toxic inorganic nutrients such as ammonium. The lowered oxygen concentrations have undoubtedly affected the natural flora and fauna of the bay.

Iliuliuk Bay, Unalaska Island is a site of increasing seafood processing. It has been speculated that the amount of processing on or near Unalaska will surpass that on Kodiak in the next few years. Large concentrations of ammonium and depletions in oxygen have already been observed in Iliuliuk Bay (Brickell and Goering, 1970), and the decomposition of seafood processing wastes, which are emptied

into the bay rather continuously, appears to be responsible for the observed changes in the nitrogen and oxygen chemistry. An examination of the ammonium concentration at stations off the mouth of the bay suggests that ammonium originating in Iliuliuk Bay influences the nitrogen economy of the surrounding ocean. However, high concentrations of ammonium, organic nitrogen, and oxygen depletion are not restricted to waters receiving waste from seafood processing plants. They can occur naturally, as evidenced by the natural phenomenon of salmon carcass decomposition which results in oxygen depletion and elevated concentrations of ammonium and other nitrogen compounds, closely simulating the industrial situation (Brickell and Goering, 1970).

Municipal Wastes

Disposal of untreated municipal wastes in the sea surrounding Alaska is common to coastal cities and villages. Household waste is the dominant component with minor contributions from small industries. Larger industries dispose of their wastes separately. The cheapest means of disposal is often used, i.e., untreated municipal wastewater is released into the open sea. In most instances this appears to have not seriously stressed the marine environment. Only in embayments with restricted circulation have minor adverse effects been documented.

Disposal of sewage into seawater affects the physical and chemical nature of coastal waters. The specific gravity of the waste products in relation to the density of seawater will determine whether the material disperses into water masses, settles to the bottom, or floats to the surface. These materials will also affect light penetration, poison plants and animals, destroy bottom habitat by settling, and destroy valuable recreation sites by floating to surfaces and washing onto beaches. More serious are the primary and secondary consequences of the chemical and biological oxidation of the organic matter. Biodegradable organic matter discharged into the sea is oxidized by microorganisms. The initial oxidation is accomplished by organisms entering with the effluent, and after dilution with seawater marine bacteria are probably the major oxidizers. The bactericidal properties of seawater are well documented (Ketchum et al., 1949). In the oxidation process, the dissolved oxygen in seawater is utilized as the electron acceptor, and when the rate of removal is greater than the rate of supply by diffusion and the photosynthetic activity of plants, the oxygen is depleted. Anoxic microorganisms begin to stabilize the remaining organic matter using the nitrate ion first, and when it is depleted, the sulfate ion, as the electron acceptors. During the latter process, noxious hydrogen sulfide is produced. The reduced compounds (e.g. hydrogen sulfide) are in reality also an oxygen debt which has to be paid before oxygen can again accumulate. In all of the biodegradation reactions carbon dioxide, ammonium, and phosphate are released into the water, and become available for organic synthesis in algal growth. Baalsrud (1967) showed that when a mixture of seawater and sewage, having a certain oxygen demand, was stored in the dark an oxidative breakdown occurred, thereby reducing the oxygen demand. However, when the mixture was inoculated with a few algae and placed in the light, algal growth gave rise to organic matter with an oxygen demand much greater than that originally found in the sewage. His experiments clearly demonstrate that the organic matter formed as a result of eutrophication potentially represents a much greater organic load than that added directly with sewage. Therefore, it appears necessary to clearly understand the secondary as well as the primary effects of sewage addition to seawater.

Cook Inlet receives untreated municipal sewage from all of the Anchorage populace, the largest metropolitan area in Alaska. The 30-foot tidal range of Cook Inlet is common knowledge. However, less known are its other characteristics, such as extreme turbulence, horizontal velocities of flow, suspended sediment loads, natural biological productivity, the effects of freshwater inflows, temperature, and wind stresses. Because of heavy sediment loads in summer and treacherous ice flows in winter, the upper inlet has not been extensively used for commercial or recreational purposes. Because of these negative properties, little concern has, until recently, been given to its capacity to assimilate man's wastes. Its strong currents and mixing, however, make it much more suitable for waste disposal than most other Alaskan systems.

In Alaska only isolated cases of water quality decline, resulting from municipal sewage discharge into the sea, have been documented. Physical, chemical and biological data indicate that some minor pollution of Cook Inlet waters near the Chester Creek and Cairn Point outfalls results from domestic sewage, but the water mass as a whole has not been adversely affected by it. Because of its extensive turbulence and heavy sediment loads, large quantities of domestic waste, as much as 7.6×10^6 m^3/day, can be discharged into the inlet without causing serious water degradation (Murphy et al., 1972). Thus a population of two to three million people could safely dispose of their domestic waste water into the inlet.

In Ketchikan, Alaska, domestic sewage disposal consists of septic tanks and drain fields, cesspools and seepage pits, or piping raw sewage into the tidewaters of Tongass Narrows (State of Alaska, 1967). Most of the sewage is believed eventually to reach salt water either by surface or underground drainage or by direct piping to points near water's edge on shore. The raw sewage outfalls are responsible for the large numbers of coliform bacteria found in the adjacent waters of Tongass Narrows, particularly Bar Harbor. The eutrophication of the waterfront area by nutrients resulting from the sewage has not been studied. Studies have indicated, however, that state bacteriological water quality standards are exceeded in many areas along the Ketchikan waterfront. Fecal solids and shredded toilet paper, which are potential health hazards as well as aesthetically offensive, are often observed along the shoreline and floating within Bar Harbor, near Bar Point and alongside the Dock, Mission, and Mill Street area. The stratification of the low density discharged sewage near the sea surface, slow nearshore tidal currents with net northward movement in Tongass Narrows, and an onshore wind component all tend to concentrate Ketchikan sewage discharges in the surface waters of the waterfront area, and to move it slowly northward past the city.

In other areas of Alaska, particularly where restricted flow of seawater is inherent or little has been done to utilize the assimilative capacity of the ocean for waste oxidation, isolated cases of water quality decline have resulted. Often, as in the case at Iliukiuk Bay, Unalaska Island, and Kodiak Island, the combined effects of fishing industry wastes and municipal sewage wastes, have resulted in low oxygen water. Low oxygen water is not, however, a very serious problem in Alaska because the environmental conditions generally prevailing lead to very high surface water concentrations of dissolved oxygen. The concentration of dissolved oxygen seems more controlled by the oceanography of the continental shelf than by locally imposed influences.

EVALUATION OF PREVIOUS PROGRAMS AND DISCUSSION OF TRENDS

Until recently, waste disposal in Alaska was done by the least expensive way. Industries and municipalities have generally discharged their primary wastes into streams, rivers, or estuaries without even the benefit of deep water outfall disperser systems. Little control of effluent quality or quantity was administered until the advent of the pulp mills in southeast Alaska and petrochemical plants in Cook Inlet.

The first modern waste disposal system in Alaska was that of the Collier Carbon and Chemical Company liquid ammonia and urea fertilizer plant located north of Kenai on the east banks of Cook Inlet. The company, after careful examination of the waters of Cook Inlet, including circulation, ammonium and nitrate cycling, and biological population assays, designed a discharge system which utilizes jet diffusers and the turbulence of the inlet to lower the concentration of the fertilizer ammonium well below harmful levels within about 10 feet of the discharge pipe. This system has operated according to design since 1969 with no evidence of harm to the environment.

Municipalities are presently facing the requirements for secondary sewage treatment before discharge into the environment. Studies conducted in connection with municipal effluents released into Cook Inlet from the city of Anchorage give no evidence that secondary treatment is necessary or even desired environmentally (Murphy et al., 1972); likewise there appears to be no reason to demand this level of treatment of other municipalities who discharge into the coastal waters of Alaska. Each situation and location should be examined to assess the capacity of the receiving waters to assimilate the planned discharge. The decision concerning secondary waste treatment plant requirements should rest on those findings. To systematically force most coastal Alaskan cities to construct secondary treatment plants when the environmental capacity to assimilate municipal waste is enormous, is not in the best public interest.

Many plants which process the fisheries products of the State of Alaska are also being forced to comply with the secondary treatment effluent requirements. In the past, these plants have discharged untreated wastes, often representing up to 75 percent of the catch by weight, into the water immediately adjacent to the plant, and have depended upon tides and scavenging organisms to keep the solid residues at a low enough level to avoid offensive surface exposure. Requirements now dictate that solids be removed and processed in some other manner. At Kodiak, the major Alaskan fishing port, many of these solid wastes are processed commercially and converted to an animal feed marketed on the west coast of the United States. The water soluble portion of the fish wastes also has considerable value for protein feed supplements, but such processing plants have not yet been constructed in Alaska. To treat these water soluble

wastes by a secondary sewage treatment process appears unadvisable for two major reasons. First, the protein in the water has high food value; and second, discharge of untreated waste through outfalls designed to keep concentration levels compatible with the environment would at least return some of the energy to the system from which it was derived, thus yielding some environmental advantage. This process could in most cases be accomplished at a lower cost.

The recent trend in Alaska, because of enforcement by government regulatory agencies to adopt effluent standards uniformly administered throughout the country with no regard to environmental quality, can only lead to devastation of Alaska's renewable resources. We must understand the ecosystems involved well enough to assess possible damage resulting from the stress of added effluents. Discharge of any amount of wastes that might result in damage to an ecosystem is foolhardy. Likewise, it is ludicrous to impose restrictions on waste discharges if it can be clearly established that the system can easily handle the loading involved without damage. If the environment itself is the real concern, as it should be, then industries must develop and install effluent discharge systems that are compatible with the environmental situation in which they find themselves rather than being forced to meet some general specified waste or water quality standard. A scientifically alert and flexible attitude toward Alaska's effluent practices is badly needed as we begin developing the state's resources. A much better understanding of the oceanography of Alaskan coastal systems should be the first priority followed by a management plan responsive to environmental needs and not political expediency.

RESULTS WHICH OFFER DIRECT USE IN ALASKAN ESTUARINE MANAGEMENT

Throughout this paper we have attempted to point out the uniqueness of the Alaskan environment and emphasize the need for better environmental understanding upon which decisions can be wisely made that will protect it, and at the same time utilize it for waste disposal and extraction of the resources needed to benefit man. The concept of trade-offs becomes important in environmental management and, in general, is a viable philosophy to be used in Alaska.

To comply with a recent NPDES permit, to become effective January 1, 1977, a urea plant at Kenai will need to spend $1,500,000 in capital improvements and consume 500,000,000 BTU's of energy per day to reduce its present ammonia effluent (about 3500 kg/day) to meet the best practical technology for ammonia effluents. Documentation has shown that the ammonia currently released by this plant is not harmful and is probably beneficial to the biota of Cook Inlet, and the revised scheme would put the ammonia into the atmosphere where the environmental hazards are much greater. The expenditure of energy and capital investments for what appears to be of questionable value environmentally, cannot be justified. Even if there was a slight environmental advantage, the justification for using large capital and amounts of energy for marginal environmental improvement is probably of negative social benefit. Other cases in Alaska could be indicated, particularly where heated effluents are concerned, in which large expenditures of both money and energy are being imposed without realizing any apparent environmental benefits.

In today's modern world social benefit must weigh heavily on decisions to utilize energy to reduce effluent concentrations unless environmental benefits can be conclusively demonstrated as a result of this energy consumption. Most effluents of the chemical industry are waste materials to that industry. They could, however, be a feed stock of considerable value to the bioengineering industry. Alaska, with its great potential for aquaculture (Kelley and Hood, 1973), should turn its attention to using these wastes for enhancement of food or marine product producing systems. Some institutional barriers will need changing for such a system to be developed, but it seems of such importance in helping meet some of man's future needs that it should be thoroughly explored and activated as soon as possible. Perhaps a more rational approach, other than imposing strict effluent standards in Alaska, would be a requirement for converting waste materials into useful feed stocks for bioengineering projects including aquaculture. Would this not be an enlightened attitude directed toward solving mankind's ever increasing needs for food supplies?

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ENVIRONMENTAL STATUS OF HAWAIIAN ESTUARIES

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ABSTRACT

Hawaiian estuaries are small but numerous, and they are of importance to the State of Hawaii. With a few exceptions, detailed environmental information about these estuaries is lacking. Circulation in the estuaries is sluggish. Many of the estuaries fail to meet water quality standards set by state law; this failure represents the combined effects of unrealistic standards governing excessive discharges. The major human stresses imposed on the estuaries are the introduction of nutrients, freshwater, and sediments. More research directed at the estuaries as total systems is needed.

INTRODUCTION

In simplest terms, an estuary is an area in which fresh and salt waters come together.* This mixing of waters has led to the development of a rich and productive coastal zone ecosystem, with an influence that extends far beyond the physiographic boundaries of the estuary. This biotic importance of estuaries, together with their widespread use for commercial and recreational purposes, mandates that a better understanding of estuarine ecosystems be available for the intelligent management and preservation of such a valuable resource.

Some Hawaiian estuaries contain beautiful quiet-water coral reef assemblages unlike any biotic community found elsewhere in the United States (Smith et al., 1973). The estuaries are breeding and spawning grounds for a variety of commercially valuable fishes (Miller, 1973; Watson and Leis, 1974). Several species of seabirds, listed as rare and endangered, inhabit the nearshore environment (Berger, in Armstrong, 1973). The estuaries are popular areas for fishing, boating, swimming, and camping. One estuary (Kaneohe Bay) also serves as the site for ongoing research by both the state and the federal governments. It is in the interest of ecology, economy, recreation, and scientific research that this report has been prepared.

According to the report by Cox and Gordon (1970), approximately 50 features in the state may be broadly classified as estuarine systems. Figure 1 is an index map of the Hawaiian Islands, and Figures 2 through 6 show each of the Hawaiian Islands which have significant estuaries. The locations of these features are noted. Most Hawaiian estuaries are small, with water areas well under 1 km^2. Existing charts for most of these features are not sufficient to show significant bathymetric or other detail. The larger estuaries and other embayments are illustrated in the atlas by Grace (1974). Even the two largest estuaries are small in comparison with their North American (or other continental) counterparts. These estuaries are important, nonetheless. Because these features are small, they are particularly vulnerable when subjected even to relatively minor environmental insults.

The total estuarine area of the state is estimated here to be about 100 km^2. It is impossible to judge accurately the coastal area outside the estuaries but within the legally defined estuarine zone; however, some limits can be imposed. If the mean width of the estuarine zone is 50 meters (surely an overestimate for most of the Hawaiian coastline), then only another 100 km^2 of estuarine zone are added to the 100 km^2 estimated for the true estuaries, bringing the total Hawaiian estuarine zone to less than 200 km^2.

This figure is probably satisfactory within the legal limits of the estuarine zone, but it is deceptive in terms of the importance of the Hawaiian coastal zone. Because the State of Hawaii as a whole is a small watershed in comparison with the North American continent, the zone of freshwater influence about the Hawaiian Islands is small in comparison with the zone of such influence off North America. In relative terms, however, the zone vulnerable to impact from activities on land may not be greatly different from Hawaii to the mainland of North

* "... the term 'estuarine zones' means an environmental system consisting of an estuary and those transitional areas which are consistently influenced or affected by water from an estuary such as, but not limited to, salt marshes, coastal and intertidal bays, harbors, lagoons, inshore waters, and channels, and the term 'estuary' means all or part of the mouth of a navigable or interstate river or stream or other body of water having unimpaired natural connection with open sea and within which the sea water is measureably diluted with fresh water derived from land drainage." (P.L. 89-753)

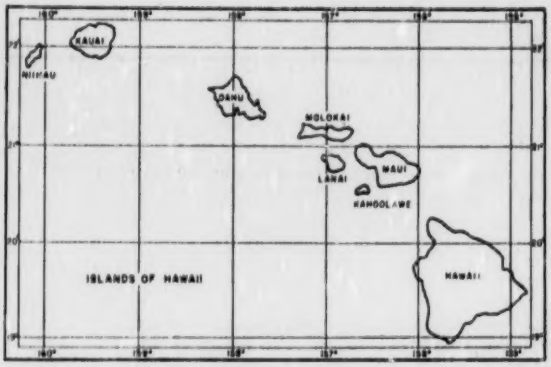

FIGURE 1.—The main islands of the Hawaiian chain. Of these, Niihau, Lanai, and Kahoolawe lack significant estuaries.

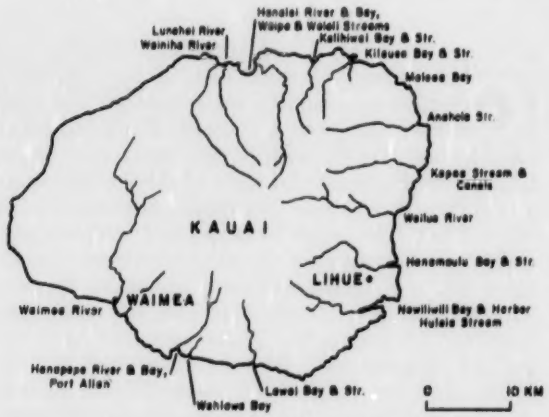

FIGURE 2.—Kauai Island, estuaries.

America. Indeed, the large bights which scallop most of the Hawaiian Islands (Figures 2-6) are already the subjects of concern to local environmental scientists and should be the subject of another report such as this one.

Table 1 helps to put the scale of Hawaiian estuaries into proper perspective. The ratio of estuarine area to the state's land area is only about half the equivalent ratio for the total United States. However, the ratio of tidal shoreline length to total land area is an order of magnitude larger for Hawaii than for the rest of the nation. That is, there is a close spatial relationship between the land of the state and the coastline.

The distribution of population is also instructive. The recent Atlas of Hawaii (Armstrong, 1973) reveals that about one-third of the state's population lives immediately adjacent to one of the major estuaries in the state. Both culture and climate have

FIGURE 3.—Oahu Island, estuaries.

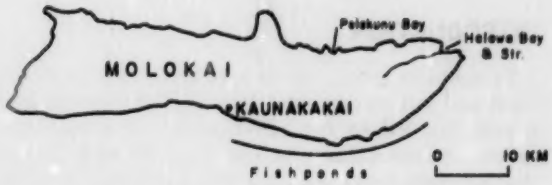

FIGURE 4.—Molokai Island, estuaries.

FIGURE 5.—Maui Island, estuaries.

acted to enhance the utilization of estuaries and the coastal zone by the people of Hawaii, so that even those persons who do not live near the water are likely to frequent it.

There are also small embayments in the state (e.g., Hanauma Bay, Oahu; Honaunau and Kealakekua Bays, Hawaii) which are renowned for their beautiful reefs. These bays are subject to insufficient freshwater inflow to qualify as estuaries, but nevertheless could be devastated with a relatively small degree of thoughtless activity. The summaries of the biology

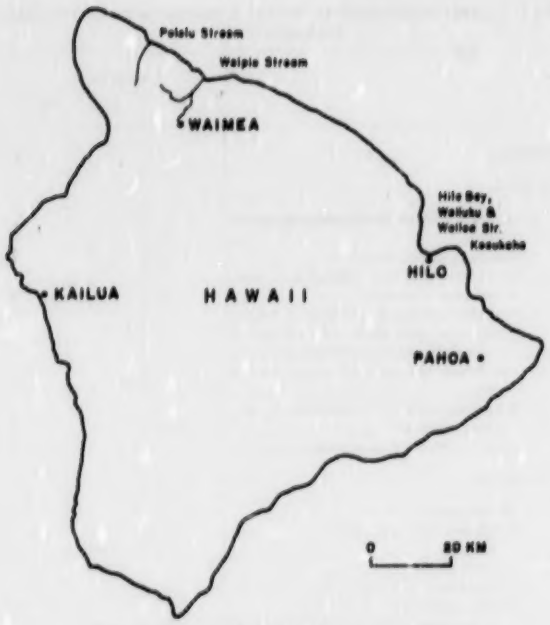

FIGURE 6.—Hawaii Island, estuaries.

Table 1.—Comparison of Hawaiian estuarine dimensions with the scale of estuaries found in the remainder of the U.S.

	U.S. exclusive of Hawaii	Hawaii
Total area (km²)	9,350,000	16,700
Estuarine area (km²)	117,000	100
Tidal shoreline (km)	136,000	1,700
Estuarine area/total area	0.013	0.006
Tidal shoreline/total area	0.015	0.10

of Kealakekua and Honaunau Bays (Doty, 1968a and b) are particularly instructive in this regard.

Kaneohe Bay is the largest well-defined embayment in the state. This embayment on the northeastern coastline of the island of Oahu (Figure 3) occupies an area of about 50 km², less than half of which is truly estuarine in character. Pearl Harbor, Oahu (Figure 3), with a water area of about 20 km², is the second largest estuary in the state and may be considered a classical estuary throughout its extent. These two estuaries are also the most widely studied Hawaiian estuarine systems, although even they are insufficiently known. Other large Hawaiian estuaries include the Keehi Lagoon/Honolulu Harbor complex, Oahu (Figure 3); Nawiliwili Harbor, Kauai (Figure 2); and Hilo Harbor, Hawaii (Figure 6). Some data on water quality and circulation are available for these last three systems, but virtually no biological information, other than hearsay and very limited biological observations, is available for these estuaries.

Because of the general lack of adequate information, an attempt to document the environmental status of the Hawaiian estuarine zone has proven to be a frustrating undertaking. Some aspects of this problem for the state as a whole have been recently summarized by Cox and Gordon (1970). That report dealt with estuarine water quality, a subject for which there is a great deal of information. Even that data base is, for the most part, insufficient for establishing trends through time. The circulation patterns of several Hawaiian estuaries have also been described, although these data have not been so recently summarized as has water quality. Quantitative information about the biological status of most Hawaiian estuaries is almost totally lacking. The biology of only two of the larger Hawaiian estuaries (Kaneohe Bay and Pearl Harbor) has been examined in any detail; some fragmented information about a few other estuaries is available. Much of the information which has been collected is difficult to locate because it is buried in private or government files. It would be well worth the expense to retrieve this information. There are numerous studies of particular Hawaiian nearshore regions aside from estuaries. As discussed above, the degree of terrestrial freshwater influence on these regions is so small that they do not qualify as part of the estuarine zone, although even these areas may be subject to damage, potentially or presently, by human activities along the Hawaiian coastline.

ESTUARINE CIRCULATION

Knowledge of the circulation of an estuary is of particular importance in assessing environmental integrity, because the characteristics of water circulation determine the residence time of pollutants in the system, or portions thereof, and hence determine the possible damage those pollutants may do to the system. There is limited information describing some aspects of circulation in numerous Hawaiian estuaries.

The most comprehensive survey to date on this subject is that of Laevastu et al., (1964), dealing with the general currents of Hawaiian inshore waters. Much of that information, plus some additional observations, is reported in the recent Marine Atlas of Hawaii (Grace, 1974). Detailed circulation studies of a few Hawaiian estuaries are available (e.g., Bathen's 1968 description of Kaneohe Bay; and Buske's 1974 description of Pearl Harbor). Most available studies of Hawaiian estuarine circula-

tion are far less comprehensive than the ones cited above, involving current measurements at only a few localities within any particular estuary and under a narrow range of oceanographic conditions.

Tidal ranges are relatively small in Hawaii (about 1 meter), and river input into estuaries is generally small. Except during periods of heavy runoff, the larger estuaries are not strongly stratified. Largely lacking the energy sources of tidal flushing and major river flow, the circulation of the estuaries is strongly related to wind patterns (e.g., Buske, 1974), to wave-driven flow into the estuarine areas (Bathen, 1968), and to tidal and wind-driven ocean currents sweeping by, outside of the estuaries (Wyrtki et al., 1967).

Despite their small size, Hawaiian estuaries generally flush rather slowly, chiefly because water movement depends, to a large extent, on the least effective of the previously-mentioned energy sources. Buske (1974) has estimated that some of the water in Pearl Harbor may have a residence time of more than four days. Dr. J. Caperon (Hawaii Institute of Marine Biology, personal communication) has suggested that water may reside in the more enclosed parts of Kaneohe Bay for several weeks. These relatively long residence times for estuarine waters and their included pollutants have obvious implications for the biota of Hawaiian estuaries and emphasize the importance of intelligent, informed estuary management.

WATER QUALITY

Water quality is surely the best-documented general environmental parameter of Hawaiian estuaries. The fact is undoubtedly true because water quality standards can be objectively spelled out, routinely measured, and thus easily legislated. Table 2 gives the state's definitions for the three coastal water classes; from best to worst, these are AA, A, and B. Cox and Gordon (1970) have summarized the water quality of Hawaiian estuaries relative to those standards, and a modified version of their summary is presented as Table 3. Several important aspects of water quality emerge from these data.

Most of the waters supposed to be pristine (AA) are considered by Cox and Gordon (1970) to be so. Kaneohe Bay is probably the most conspicuous exception to this generality. It is obvious from the data presented by Cox and Gordon that as soon as some deterioration of water quality is permitted or occurs (to class A or B), there is little chance that even these lower standards will be met. Over half the estuaries assessed by Cox and Gordon

Table 2.—Water quality standards pertinent to Hawaiian estuaries. From Cox and Gordon (1970)

	Class of water		
	AA	A	B
Substance			
A. BASIC			
1. Settleable materials forming objectionable deposits	0	0	0
2. Floating debris, oil, scum, etc.	0	0	0
3. Substances producing objectionable color, odor, taste or turbidity	0	0	0
4. Materials, including radionuclides, in concentrations or combinations which are toxic or produce undesirable physiological responses in human, fish and other animal life and plants	0	0	0
5. Substances, conditions, or combinations producing undesirable aquatic life	0	0	0
6. Soil from controllable accelerated erosion	0	0	0
B. SPECIFIC			
1. Microbiological			
A. Coliform bacteria (/100 ml)			
Median	≤ 70	1000	
Upper decile	≤	2400	
Maximum	≤ 230		
B. Fecal coliforms			
30-day mean	≤ 200	400	
30-day upper decile	≤ 400	1000	
2. pH			
Departure from natural	≤ 0.5	0.5	0.5
Maximum except from natural causes	≤ 8.5	8.5	8.5
Minimum except from natural causes	> 8.0	7.0	7.0
(except fresh tidal water)	≥ 7.0		
3. Nutrients (mg/liter)			
Total phosphorus	≤ 0.020	0.025	0.030
Total nitrogen	≤ 0.10	0.15	0.20
4. Dissolved oxygen (mg/liter)			
(except from natural causes)	≥ 6.0	5.0	4.5
5. Total dissolved solids.			
TDS departure from natural (% of natural fluctuation)	10		
TDS (mg/liter)	≤ 28,000		
6. Temperature (°F)			
Departure from natural	≤ 1.5	1.5	1.5
7. Turbidity			
Secchi disk extinction coefficient, departure from normal (%)	≤ 5	10	20
8. Radionuclides			
(MPCn values by NBS)	≤ 1/30	1/30	1/30
(concentration)	≤ USPHS values for drinking water		
(concentration in harvested organisms)	≤ Federal Radiation Council recommended limits		

Table 3.—Summary of water quality relative to standards for coastal waters. Modified from Cox and Gordon (1970)

Class of water	Total* estuaries	Number probably meeting standards	Number probably not meeting standards	Number with insufficient data
AA	14	11	3	0
A	65	5	39	21
B	10	1	5	4
Total	89	17	47	25

* Estuaries with two or more classes of water quality receive multiple listing in this table.

apparently fail to meet the legislated water quality standards, and most of the violations involve class A waters. Most of the class B waters for which data are available fail to meet even these very permissive standards. Even though water quality has been cited as the best-known environmental aspect of the Hawaiian estuaries, with rare exception, the knowledge of water quality is also, in itself, insufficient to point to either trends of water quality change with time for a particular estuary or spatial trends within the estuary.

Some of the failure to meet legislated standards lies with the standards themselves; they are artificially imposed water quality limits with little allowance for natural variations within those limits. For example, some nearshore areas with natural freshwater seeps may locally exhibit salinities and nutrient levels outside the legislated limits (e.g., Honaunau Bay; Doty, 1968). Natural freshwater seepage may contain, for instance, many times as much phosphate as open ocean waters, which form the basis for legislation. Moreover, departures from legislated limits may not harm particular environments. In other instances these standards are probably too permissive for maintaining biological integrity. We must conclude that water quality standards are not adequate measures of estuarine biological integrity.

Table 4.—Summary of recurrent stresses, by island*

Development	Kauai	Oahu	Molokai	Maui	Hawaii	Total
Water	12***	6	0	8	3	29
Agricultural						
Sugar cane	12	5	0	2	3	22
Pineapple	1	3	0	4	0	8
Taro	4	1	0	1	1	7
Ranching	14	7	1	6	0	28
Miscellaneous	0	1	0	0	0	1
Industrial						
Sugar factory	1	1	0	0	1	3
Pineapple factory	1	1	0	1	0	3
Petroleum refinery	0	1	0	0	0	1
Thermal discharge	1	2	0	1	0	4
Quarry	1	0	0	0	0	1
Miscellaneous	1	5	0	1	1	8
Urban						
Sanitary sewage	2	8	0	1	1	12
Urban cesspools	9	11	0	2	1	23
Estuarine						
Commercial/military harbor	2	3	0	1	1	7
Small boat harbor	2	5	0	1	1	9
Sewage outfall	2	5	0	1	1	9
Fishing**	2	2	0	0	1	5
Recreational**	8	9	0	0	1	18
Number of Estuarine Systems	15	12	3	11	4	45

* Hilhau, Lanai, and Kahoolawe do not have significant estuaries.

** Some fishing and recreational use occurs in most Hawaiian estuaries. The estuaries listed experience heavy use.

*** These numbers represent the number of estuaries subjected to each kind of development.

RESOURCE DEVELOPMENT RELATED TO HAWAIIAN ESTUARIES

Cox and Gordon (1970) summarized the resource development pertaining to Hawaiian estuaries. Their list, divided into various estuarine types within each estuarine system, is summarized here in terms of the 45 major estuarine systems within the state. The resource developments can be broadly divided into water, agricultural, industrial, urban, and estuary; and each of these divisions can in turn be subdivided.

Table 4 lists the divisions and subdivisions of resource development and their distribution. Water development, almost entirely in the form of irrigation or storage, appears to be the least disruptive use of the resources. It simply involves reduction of water flow into the estuaries, with consequent potential alteration of salinity and circulation patterns. Most of the estuaries in the state experience some water loss or diversion for irrigation.

A variety of agricultural developments is felt by estuaries of the state. Moreover, the open-coast, non-estuarine zones are subject to much the same developments. Ranching and sugar cane cultivation are the two most recurrent agricultural developments affecting Hawaiian estuaries, with most estuaries receiving materials from one or more of these.

Industrial developments are about as diverse as the agricultural activities but are much more localized. There are miscellaneous industrial developments, primarily on the island of Oahu. The three major discrete categories of insults from industry are thermal discharges, discharges from sugar factories, and discharges from pineapple factories. It should be emphasized that these three activities also exert profound influence on the open coastline. The major thermal effect is simply that of heating the receiving water. Discharges from sugar factories include sediment, bagasse and other cane trash, nutrients, soluble organics, and bacteria. The pineapple factory discharges include pineapple wastes and soluble organics.

Urban discharges affect most Hawaiian estuaries. Those areas with sanitary sewage disposal will nevertheless contribute trash, detergents, miscellaneous industrial pollutants, nutrients, and bacteria during any period of runoff (i.e., heavy rains). Those areas served with cesspools will contribute all of the above pollutants, at higher levels. Most urban areas, but particularly the multiplying hous-

ing developments less than 10 years old, are particularly susceptible to the erosion and runoff of large volumes of water and sediment.

The last category of resource development is that of the estuaries themselves. In terms of numbers of estuaries affected, various recreational uses prevail. These activities, as well as fishing, introduce miscellaneous boat sewage and trash into the waters. The uses of estuaries in the state for commercial/military harbors and small boat harbors contribute the same kind of wastes (but in larger amounts than recreational uses) plus oil, bilge discharges, industrial pollutants of various forms (including heavy metals), and disruptive activities from dredging. The stirring of the water column and sediment has been recently pointed out as almost certainly important (Evans et al., 1974), but it is not clear whether the net effect of this activity is beneficial or deliterious.

EFFECTS OF RESOURCE DEVELOPMENT ON HAWAIIAN ESTUARINE BIOTA

Available information is inadequate for providing an assessment of the biological status of most Hawaiian estuaries. Only Pearl Harbor and Kaneohe Bay have been studied in any detail. Hence an alternative approach for discussing the status of these communities is taken. The various resource developments listed in Table 4 lead to a relatively small variety of kinds of stresses (or stimuli) to which the environment is subjected. It is possible either to document or to speculate how the biotic communities could be expected to respond to these stimuli. The stresses considered here include salinity variation, sediment discharges, nutrient enrichment, and thermal enrichment. Insufficient data are available for tropical organisms to judge the damages from oil, heavy metal, or biocide pollution, but these and related stresses are judged from evidence elsewhere to be severely detrimental to marine life.

Hawaiian estuaries are subjected to two directions of salinity variation by human intervention. Use of stream water for irrigation lowers discharges into numerous Hawaiian estuaries, hence raises their salinities. Timbol (1972) studied the species distribution of Kahana estuary (Oahu) and determined the salinity tolerances of selected species. Over the salinity range examined (9 to 19‰ (parts per thousand), or 25 to 50 percent oceanic salinity) the number of species increases with increasing salinity. It is safe to assume that below 9‰, the species count increases with decreasing salinity as freshwater organisms became dominant. If the bulk of Hawaiian estuarine waters are considered to be more saline than 9‰, then lowering the discharges of stream water into the estuaries should cause an intrusion of marine organisms into the estuaries.

There is another, perhaps more devastating, salinity variation imposed upon some Hawaiian estuaries—that of high freshwater runoff. The effect has been well-documented in Kaneohe Bay, where changing patterns of land usage (including paving a substantial portion of the watershed and baring many acres of topsoil during the construction of housing) have resulted in tremendous flood discharge into that bay. Banner (1974) has demonstrated that such runoff creates a freshwater wedge on top of the more dense seawater. During a single storm in 1965, such a wedge killed marine organisms (most conspicuously corals) to a depth of almost two meters in some portions of the bay. Unpublished studies by Smith, Jokiel, Key, and Guinther (Hawaii Institute of Marine Biology) suggest that biotic microcosms typical of shallow water communities found in the bay can survive two or more days of salinities as low as 25‰ with little damage, but that salinities below 20‰ are immediately detrimental to most of the biota. Hence, such freshwater discharges lowering the salinity to near 0‰ can be expected to be immediately damaging to intertidal and immediate subtidal biota in the marine portions of the estuaries.

Sediment discharges into Hawaiian estuaries are a conspicuous parameter arising from numerous human activities. As described above, runoff from changing land use is a prominent feature along much of Hawaii's coastline. Many streams have been channelized in urban developments and are now more prone to flooding (Banner, 1974). That runoff tends to run red with Hawaiian soil. At least one industry—sugar milling—presently contributes substantial amounts of sediments (mostly to the open coast rather than to estuaries). Again, data from Kaneohe Bay are instructive. Roy (1970) estimated that 100 thousand tons of land-derived sediment per year are being deposited in that bay. Later estimates of the fraction of Kaneohe Bay sediments which are land-derived (Smith et al., 1973) indicate that Roy's figure may be low by a factor of two.

Such sediment inputs are deliterious to estuarine biota in a number of ways. They may directly smother corals and other organisms which live at the interface between the substratum and the waters of estuaries. They may contain material toxic or noxious to the biota. In the water they may block the light from those organisms which photosynthesize organic products. They may foul the feeding mechnisms of those organisms which filter food from the water. Organic material in the sediments may alter

the food-web relationships of the community in question.

Another form of sediment input appears to be fading from the Hawaiian scene—the discharge of finely-milled cane trash (bagasse) from sugar mills. Grigg (1972) has demonstrated that even on open coastlines there may be tens of meters of accumulated bagasse on the sea floor offshore from these mills. Coral-reef communities subjected to such inputs have been completely demolished. This material is now finding use in the sugar industry as a valuable fuel (R. Webb, Hilo Coast Processing Company, personal communication), so this input should terminate. Grigg's data demonstrate that the material flushes from the open coasts within a few years after the bagasse input stops. As yet, the time required for community recovery is unknown. Biotic population of submerged lava flows is apparently measured in decades (Grigg and Maragos, 1973). The flushing and repopulation characteristics of an estuary may not be even that *rapid*.

Most Hawaiian estuaries are probably subjected to some nutrient enrichment. Of course, elevated nutrient levels are characteristic of most estuarine systems, and this is one reason (as previously mentioned) that even some unpolluted waters of the state may fail to meet the legislated water quality criteria. Nevertheless, it seems likely that Hawaiian estuaries may not naturally experience the levels of eutrophication which typify mainland estuarine systems. Caperon et al., (1971) have demonstrated that the southern end of Kaneohe Bay is a highly eutrophic system which is apparently not limited by nutrient levels in the water, and Krasnick (1973) has shown that this eutrophication has increased the primary productivity of that bay over the past decade. A bulbous green alga which may be found as small fist-sized masses on most Pacific coral reefs, has grown to gargantuan size (some masses being a meter or more across) in Kaneohe Bay, apparently in response to this eutrophication (Banner, 1974; Soegiarto, 1972; Smith et al., 1973). There is evidence (Banner, 1974; Maragos, 1972) that this alga has severely damaged the coral community of the bay and has also otherwise altered the community structure of the reefs. The growth of the alga is likely to represent the combined effects of high nutrients and low grazing pressures by fishes or other reef herbivores.

Pearl Harbor is another estuary which has been subjected to high nutrient inputs. Apparently phytoplankton blooms ("red tides") are occurring with increasing frequency and over an increasing portion of that harbor. (Evans et al., 1974).

Some Hawaiian waters are subjected to thermal enrichment. Until recent studies by Jokiel et al., (1974) and Jokiel and Coles (1974) it had been assumed that Hawaii, with its largely tropical biota in a subtropical setting would probably not be greatly damaged by thermal enrichment. That does not seem to be the case. Summertime ambient temperatures are about 27°C, and that temperature is about the optimum temperature for corals and, apparently, for other biota found on Hawaiian reefs. These organisms may be able to tolerate an enrichment of 1 or 2°C above ambient, but further temperature elevations are detrimental. Even open water reefs have been damaged by thermal enrichment (Jokiel and Coles, 1974), albeit very locally.

Table 5 lists the various resource developments, the number of estuaries subjected to each, and the likely stresses from each. The column sums provide an index of the relative importance of the various stresses on Hawaiian biota. Nutrient enrichment, decreased salinity, and sediments are by far the most recurrent stresses imposed upon the estuarine communities. Inputs of biocides and heavy metals are also important. Only 45 estuarine systems were used in the construction of Table 4, hence Table 5; yet all of the above insults appear over 45 times in Table 5. This situation addresses the fact that the estuaries are for the most part subjected to multiple stresses—a consideration which will probably make the job of removing insults all the more difficult.

Table 6 summarizes the expected biotic responses to five major stresses. It is clear that more experimental data are sorely needed to verify most of these responses in tropical communities. Equally needed is an improved data base describing the Hawaiian estuaries. In particular, there appears to be a lack of foresight in obtaining baseline data before any projected environmental alteration—whether that alteration is predicted to be good, bad, or benign—or to combine that data with post-alteration descriptions, in order to describe the biotic responses to that alteration.

NEEDS FOR ENVIRONMENTAL MANAGEMENT OF HAWAIIAN ESTUARINE SYSTEMS

Table 5 suggests that nutrients may be the primary stressing parameter imposed upon Hawaiian estuaries. Virtually every human activity appears to have the potential of delivering nutrients to these estuaries. Thus, any regulation to lower discharges appears likely to improve the nutrient status of Hawaiian nearshore waters. Various considerations suggest that a change from uncontrolled nutrient input to controlled input may be as satisfactory as

Table 5.—Stresses imposed by various resource developments.

	No. of estuaries	Decreased salinity	Increased salinity	Sediment	Bagasse	Nutrients	Thermal	Oil	Metals	Biocides
Water	29		×							
Agriculture										
Sugar cane	22	×		×		×				×
Pineapple	8	×		×		×				×
Taro	7	×		×		×				×
Ranching	28	×		×		×				
Miscellaneous	1	×		×		×				×
Industry										
Sugar	3	×		×	×	×				
Pineapple	3	×				×				
Petroleum	1							×		
Thermal	4						×			
Quarry	1			×						
Miscellaneous	8	×		×		×				
Urban										
Sanitary sewage	12	×		×		×			×	×
Cesspool	23	×		×		×			×	×
Estuaries										
Commercial/military harbor	7					×		×	×	
Small boats	9					×		×	×	
Sewage	9	×				×			×	
Fishing	5					×				
Recreational	18					×				
Total		124	29	113	3	163	4	17	60	73

no input—or perhaps more satisfactory. Without going into these considerations, suffice it to point out that the uncontrolled discharge of nutrient-laden water into Hawaiian estuaries must be slowed if these environments are to be preserved and maintained. Improved sewage treatment facilities are a major move in the direction of controlling this nutrient flow. The State of Hawaii is moving toward this goal. Discharges of treated or untreated sewage into the estuaries must stop. Indeed, federal and local agencies are working towards this goal; the 15,000 m³/day of sewage presently being discharged into Kaneohe Bay is scheduled to be diverted by the end of 1977. Runoff from agricultural regions may be more difficult to control, but it should be minimized. Dumping of material from ships is a debatable practice at sea; in harbors, it should not be allowed.

Slowing the freshwater and nutrient inputs into the estuaries should simultaneously stop much of the sediment input. Hence that input need not be discussed as a separate topic.

Finally, more data are needed. The water quality data, which are collected routinely, are certainly vital, but they do not substitute for an adequate knowledge of the organisms themselves. Because biotic data are more difficult to gather, the techniques for gathering and reporting these data should be increasingly researched and developed. Some sort of local data bank for central storage of these data is also needed; with adequate funding, the Hawaii Coastal Zone Data Bank (University of Hawaii) could serve that function. Increased funding is necessary to demonstrate quantitatively the biotic responses to various environmental stresses. Such work should include both field observation and laboratory experimentation. The biotic experimental and observational work cannot be expected to yield

Table 6.—Likely effects of major stresses on estuarine biota.

Nutrient Enrichment

Eutrophication, algal blooms (benthic and planktonic), oxygen stress, alteration of community structure through food-web modification or competitive pressures, buildup of organic material in sediment.

Lowered Salinity

Abrupt destruction of marine communities.

Sedimentation

Smothering, light blockage, blockage of feeding mechanisms, introduction of adsorbed toxicants.

Biocides

Possible abrupt destruction of marine communities or portions thereof. Buildup in marine organisms, with possible long-term effects on these organisms or on man.

Heavy Metals

Similar to biocide effects.

short-term results. Because of the great disparity in the longevities of organisms in any community, the total community responses to external stimuli take years. Therefore, the necessary field or laboratory observation times must be of similar magnitude. Particular attention needs to be paid to low stress levels as they affect total communities. The day of assessing environmental insults from lethal bioassays over periods of days on a few arbitrarily chosen organisms should be over. For the most part, Hawaiian estuaries, or any other ones for that matter, are not subjected to that kind of stress regime. Yet Hawaiian estuaries are obviously changing in response to human perturbations. A new look is necessary to learn why.

It is certainly desirable that EPA fund a portion of the much-needed research, but other federal, state, and local governmental agencies, and private industries should fund environmental research as it pertains to the effects of their activities on the estuarine environment. Much of this funding could be handled in terms of some kind of "blind trust" and be administered by an appropriate agency, so that the funding agencies or industries could not be questioned about their influence on the research.

Multidisciplinary, total-system research and monitoring must be encouraged and amply funded. It is the lack of efforts such as these which makes realistic assessment of the total environment not entirely satisfactory. Research by the Hawaii Environmental Simulation Laboratory (University of Hawaii) is a step in the right direction. Their work is also not entirely satisfactory; it concentrates primarily on terrestrial considerations (hence inputs to estuaries) without adequate consideration of effects on receiving waters and their biota. Nevertheless, that kind of study carries the needed potential for interaction between research units and governmental planning agencies. That kind of effort needs expansion to include the marine environment.

The small size of both the Hawaiian estuaries and the watershed draining into them makes these systems particularly tractable to total-system description and analysis. It is therefore appropriate that Hawaii be the site for concentrated efforts to describe and improve the environmental status of estuaries.

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This paper is Contribution No. 470 of the Hawaii Institute of Marine Biology.

INDUSTRIALIZATION EFFECTS

THE EFFECTS OF INDUSTRIALIZATION ON THE ESTUARY

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ABSTRACT

Industrial dependence on the estuary is restricted to those industries which rely on the estuary for waterborne transportation, for process water, or for products derived from the estuarine waters or bottom sediments. Among these, crude oil handling, refineries and petrochemical plants, utilities, iron and steel production, paper manufacturing, and sand and gravel extraction are the more important industries. Channel dredging, spoil disposal, and a wide range of pollutants resulting from industrial discharge are described.

Responsible federal agencies seem to be approaching the problem of industrial pollution from the perspective of reducing impacts by adopting water quality standards. In the short term, that is the most expedient solution. In the longer term, though, we must assess the possibility of reducing impacts by relocating certain estuarine-dependent industrial centers to new, more environmentally acceptable sites.

INTRODUCTION

When the United States was still an agriculture based society, ports were developed to transport goods and products from the hinterland. Ports were generally located as far inland as possible and road-rail transport systems were developed in response to port location. As the country evolved into an industrialized society, these ports became the hubs of industrial activity. Industrialists took advantage of the fact that water transportation for the shipment of raw materials and products was cheap, the harbors contained abundant water for cooling and waste disposal, and a supply of workers was already available. Through the late 19th and early 20th centuries, industrial activity, the quantity and diversity of effluents, and the population all increased around these ports. Technology of ship construction developed so that drafts of larger ships grew beyond the water depths in most of these ports. Because major industries were located at the ports, large dredging programs were undertaken to deepen the channels. After the channels were deepened, new industries had to locate along them to receive or ship materials.

Throughout the development phase of the ports, occasional fish kills would occur and there was a general decline in commercial fishery production of our estuaries. Beginning in the mid-20th century, researchers studying estuarine processes began to document the biological importance of the estuary as a spawning and nursery ground for a significant part of the entire coastal area. Oceanographers learned that circulation of waters in estuaries is generally weak, and that they have a limited capacity to absorb pollutants.

We find ourselves in the present situation of having major industrial centers, dependent on water transportation, located on estuaries which are not deep enough to handle modern ships, are not large enough to assimilate wastes, and which are incredibly valuable as a biological-recreational natural resource.

When dealing with the effects of industrialization on the estuary, this paper will address those problems unique to estuarine areas which have arisen through increasing industrial activities in the estuarine environment, and will delineate individual industrial-estuarine pollution problems and discuss possible solution. More specifically, the report will examine pollution problems in estuaries, identify factors that actually pollute, investigate the effect of control on the estuarine environment as a whole including human activities, and describe the procedures, if possible, for gaining control of such factors. For the purposes of this report, the period from 1970 to the present will be emphasized.

This paper will not deal with pollution resulting directly from agricultural activity, from domestic sewage or from non-point source discharges such as storm runoff. Industrial effluents discharged into the freshwaters or the nation's air and carried to the estuary will not be considered.

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INDUSTRIAL DEPENDENCE ON THE ESTUARY

Uses and Projections

For purposes of this study, industrial "dependence" on the estuary will be restricted to those industries which rely on the estuary for waterborne transportation, for process water, or for products derived from the estuarine waters or bottom sediments.

Waterborne transportation of bulk materials for the year 1971 is summarized in Table 1. Data are presented for coastal U.S. ports, excluding the Great Lakes.

Our basic industries (petroleum, coal and coke, iron and steel) are the principal users of our coastal waterways both for foreign and domestic commerce (sand and gravel are significant commodities in domestic commerce). The transportation of large quantities of these bulk commodities implies that related processing/refining/utilizing industries are also located on our coastal waterways. From the point of view of marine transportation, we have at least three candidate industrial complexes which are dependent on the estuary:

1. Crude oil handling, associated refineries, and petrochemical plants;
2. Iron, steel, and closely allied metal fabricating industries; and
3. Industries using coal, coke, asphalt, and tar either as an energy source or as a raw material.

An estimate of the kinds of industries dependent on large volumes of process and/or cooling water can be obtained by examining Table 2. Industries having major surface discharges have been categorized by the EPA. Three of these industries, the chemical, paper, and utilities industries represent 47 percent of the major industrial discharges to the surface waters of the United States. Some of these large water users are the same ones which utilize the estuary for transportation. These include the iron and steel (including metal fabricating) and petroleum and coal industries. The chemical industry (including inorganic acids and salts, organic fibers, plastics and pigments, and drugs, cosmetics and soaps), paper industry, and utilities industry have been added to the list.

Table 1.—Total waterborne commerce (Calendar, 1971). Coastal ports of the United States (millions of short tons).

	Foreign	Domestic
Total	506.5	242.9
Imports	333.8	—
Exports	172.7	—
Petroleum and Products	38.7%	44.0%
Coal and Coke	11.7%	14.9%
Iron Ore and Steel	12.5%	8.2%
Sand, Gravel and Stone	2.2%	12.1%
Grain	6.8%	2.0%
Chemicals	5.8%	5.2%
Logs and Lumber	3.8%	2.5%
All Others	18.5%	11.1%

Table 2.—Industrial discharges by industry group*

	Number of Permits
Chemical and Allied Products	522
Paper and Allied Products	407
Electric and Gas Utilities	392
Textiles	151
Fabricated Metal Products	149
Iron and Steel	142
Petroleum and Coal Products	136
All Others	902

* Source: National Water Quality Inventory, 1974

The third group of industries which are estuarine dependent are those which extract materials directly from the water or bottom of the estuary. Desalinization plants extract fresh water from estuaries while other industries extract bromine, magnesium, calcium, and sodium that is dissolved in the waters of the estuary. Sea shells (a source of calcium and lime), and sand and gravel, are taken in large quantities from the bottom of our nation's estuaries.

Industry Projections

Where data are available, projections for future requirements in each of the estuary dependent industries have been made. These projections are for the entire industry in each case, and do not necessarily indicate the pressure to locate new facilities on estuaries.

The industry profiles for petroleum refining, petrochemical manufacturing, and paper products have been developed by D. M. Bragg, associate research engineer, Industrial Economics Research Division, Texas A & M University and have been extracted here with the author's permission.

PETROLEUM REFINING

In the U.S. today, there are 247 petroleum refineries with an average daily capacity of 57,555 barrels. Three refineries have capacities of over 400,000 barrels per day each and four have over 300,000. Many of these refineries can be expanded but some cannot—either because of limitations of space or

Table 3.—Refineries planned but not constructed

Company	Location	Size (B/D)	Final Action Blocking Project
Shell Oil Co.	Delaware Bay, Del.	150,000	State Reacted by Legislature Passing Bill Forbidding Refineries in Coastal Area.
Fuels Desulfurization (1)	Riverhead, L.I.	200,000	City Council Opposed Project and Would Not Change Zoning.
Maine Clean Fuels (1)	South Portland, Me.	200,000	City Council Rejected Proposal.
Maine Clean Fuels (1)	Searsport, Me.	200,000	Maine Environmental Protection Board Rejected Proposal.
Georgia Refining Co. (1)	Brunswick, Ga.	200,000	Blocked Through Actions of Office of State Environmental Director.
Northeast Petroleum	Tiverton, R.I.	65,000	City Council Rejected Proposal.
Supermarine, Inc.	Hoboken, N.J.	100,000	Hoboken Project Withdrawn Under Pressure From Environmentalist Groups. Considering State Near Paulsboro, N.J.
Commerce Oil	Jamestown Island, R.I. Narragansett Bay	50,000	Opposed by Local Organizations and Contested in Court.
Steuart Petroleum (2)	Piney Point, Md.	100,000	Withdrawn Due to Pressure From Environmental Groups.
Olympic Oil Refineries, Inc.	Durham, N.H.	400,000	Withdrawn After Rejection by Local Referendum.

(1) Maine Clean Fuels and Georgia Refining Company and subsidiaries of Fuels Desulfurization and the refinery in question is the same in each case, so the capacity in B/D is not additive, but the incidents are independent and additive.

(2) Again being introduced.

Source: "Trends in Refinery Capacity and Utilization," Federal Energy Office, Washington, D.C., June, 1974.

because they are not well sited logistically to meet the increasing demand.

The gulf coast currently has 16 percent of the U.S. demand but has approximately 40 percent of the country's refining capacity. On the other hand, the east coast has 40 percent of the demand but only 12 percent of the refining capacity. Based on assessments of site availability and limitations arising from environmental pressures, it is now anticipated that a number of the new refineries, which otherwise would have been built in the east, will be constructed instead on the gulf coast. Table 3 lists a large number of announced or planned refinery projects which have been postponed or have doubtful promise. It is significant to note that all of the refinery sites listed in Table 3 are located along estuaries.

PETROCHEMICAL MANUFACTURING

Historically, petrochemical production has been closely tied to the output of natural gas liquids (NGL) produced in natural gas processing plants. In these plants natural gas, comprised of over 90 percent methane, is stripped of its butane, propane and part of its methane.

As a result of the decreasing supply and increasing price of NGL, the future expansion of olefin manufacturing facilities will be based almost exclusively on heavy oil feedstocks. Facilities using heavy oil feedstocks accounted for only 12 percent of all ethylene produced in 1970. This type of production will be up to 24 percent of the total by 1975; and by 1980, it is expected that just under 50 percent of all ethylene produced will be generated from heavy liquids. As a result, consumption of heavy liquids in the manufacture of olefins will rise from 130,000 barrels a day at present to 780,000 barrels a day by 1980. The heavy liquids, such as naptha and gas oil, are produced from petroleum. And, because of this, the locations of future petrochemical complexes will be even more closely linked to those of oil refineries than in the past.

The location of future expansion in the industry will be determined more by the availability of feedstocks than by any other factor. In view of the transition to heavy cracker feedstocks, potential feedstock availability will increasingly be determined by refinery location which, in turn, will be determined by crude oil supply. Therefore, the gulf coast would no longer continue to have a clear-cut locational advantage, and the advantages of freight savings on finished products should make the east coast a more attractive location. If the oil refining capacity of the east coast experiences large increases, then a strong likelihood exists that there would be a corresponding increase in basic petrochemical capacity in the region.

ELECTRIC POWER

Fossil and nuclear energy sources form the basis for almost all U.S. electric production. Presently designed systems generate large quantities of waste

Table 4.—Growth of summer peak electric demand 1974-1983 as projected by regional reliability councils April 1, 1974; contiguous United States

Year	MW	Annual Increase (%)
1974	364,244	—
1975	394,005	8.17
1976	427,995	8.63
1977	460,377	7.57
1978	494,848	7.49
1979	531,699	7.45
1980	570,798	7.35
1981	612,252	7.26
1982	656,793	7.27
1983	703,774	7.15

Source: Federal Power Commission, Bureau of Power Staff Report, June 24, 1974.

heat which must be removed from the plant site, either by cooling towers, cooling ponds, or once-through cooling with discharge into a body of water.

Demand for electrical energy, recently revised downward due to conservation practices resulting from the "energy crisis" are presented in Table 4.

A fossil fuel plant with once-through cooling requires about 600 gallons per minute (GPM) of cooling water for each megawatt (MW) of electricity produced. Nuclear plants require about 900 GPM of cooling water per MW of electricity. Some of the waste heat of fossil plants goes directly up the stack but nuclear plants dissipate almost all their waste heat through the cooling system. In both cases, the temperature of the discharged water would be 15°F higher than the intake water.

Environmentalists had initially been most concerned with thermal pollution of estuaries because of the large volumes of hot water discharged. It now appears that the major impact of once-through cooling is not thermal pollution of the discharged water but the killing of most or all of the organisms sucked up by the pumps and passed through the plant. Fortunately, the installation of cooling towers can reduce the quantity of water required to 1 to 3 percent of the volume needed for once-through cooling.

> The solutions to this critical problem are: (1) to locate power plants along the open coast where there is deep-water nearby for strategic placement of intake and outlet structures, and, (2) to reduce the volume of cooling water by requiring plants to use closed cycle systems which recirculate cooling waters, rather than the open cycle systems which continuously withdraw and discharge large volumes of water from the environment (Clark and Brownell, "Electric Power Plants in the Coastal Zone," American Littoral Society Publication #7, 1973.)

Power generation facilities can be sited on the coast; they do not require docks, large labor forces, downstream or satellite industries and their product can be shipped over long distances at modest cost.

Paper Products

Demand for paper and paper products has increased about 3.5 percent per year. Capacity estimates for the 730 paper plants are presented in Table 5.

In addition to the basic fiber raw materials, water and limestone are used in paper making. The limestone can be acquired from either mines or oyster shells. Both sources are used quite extensively, depending upon the proximity of the source, the abundance of the material, and other factors.

There are two major papermaking processes, the sulfite and the kraft. The sulfite process, however, is a major water polluter and is gradually being phased out. Although the kraft process does not pollute water as does the sulfite method, it has an odor problem resulting from the sulphur used in manufacturing.

Large quantities of wastewater are discharged into rivers and streams. Pollutants are either stripped from the discharge or nullified by sufficient treatment. Solid wastes, such as bark and particulates, are burned.

Sand and Gravel Production

These products, used for fill, building, and paving amounted to 944 million tons in 1970. About 90 million tons were mined from the estuaries of the U.S. in that year. As land values increase in onshore areas and as industry recognizes that large quantities of sand and gravel occur offshore and in our estuaries there will be increasing pressure to utilize these materials.

Table 5.—United States paper and paperboard capacity; annual summary 1972-1976 (thousands of short tons)

Grades	1972	1973	1974	1975	1976
Total All Grades Paper and Paperboard	61,868	64,431	66,098	68,377	69,736
Total Paper	26,545	27,394	27,954	28,633	29,125
Total Paperboard	29,328	30,565	31,482	32,986	33,749
Total Construction Paper and Board and Other	5,995	6,472	6,662	6,776	6,862

Source: "1972-1975 Capacity Survey," American Paper Institute, New York, N.Y., May, 1974.

IRON AND STEEL MANUFACTURING

Since 1950, the demand for metals in the United States has tripled. By the year 2000 it is expected to triple again. Recent forecasts put crude steel requirements by the year 2000 at 293 million tons for the United States.

Total iron ore requirements for the United States should reach 156 million tons per year by the year 2000. As Table 6 shows, imports of foreign iron ore through east coast ports should attain an annual level of 37.8 million tons by the same year, nearly one-fourth of United States consumption. It seems as though there will be increased reliance on foreign ore, shipped by water to U.S. ports, and presumably, processed there.

ENVIRONMENTAL EFFECTS OF INDUSTRIALIZATION OF THE ESTUARY

The environmental effects of industrialization include physical modifications of the estuary, the introduction of substances toxic or harmful to aquatic organisms, and the introduction of materials hazardous to human health or which impact aesthetic values.

Physical Modification of the Estuary

Our ports are located at or near the heads of estuaries and channels need to be dredged and maintained to serve these ports. The size of ships serving U.S. ports projected to the year 2000 is presented in Table 7. Note particularly the draft of the vessels.

The maximum channel depth of any U.S. harbor is 45 feet. It is quite clear that a large amount of dredging must be accomplished or the docking facilities must be moved out of the upper reaches of our estuaries. Investment in existing harbors is quite large (Table 8) and will serve as a deterrent to moving the facilities.

Of the total investment for these U.S. harbors, a significant portion is expended for dredging and related spoil disposal activities.

> The Corps of Engineers, in fulfilling its mission in the development and maintenance of these (navigable) waterways, is responsible for the dredging of large volumes of sediment each year. Annual quantities are currently averaging about 300,000,000 cubic yards of maintenance dredging operations and about 80,000,000 cubic yards in new work dredging operations with the total annual cost now exceeding $150,000,000. (Boyd et al. Corps. Tech. Rpt. H-72-8).

Table 6.—Tonnage of iron ore imports to North Atlantic by origin and destination (millions of short tons)

Destination	1970	1980	1990	2000
Baltimore	9.2	14.8	17.3	20.3
Delaware River	12.5	14.1	16.6	17.5
Total	21.7	28.9	33.9	37.8

Source: "Interim Report—Atlantic Coast Deep Water Port Facilities Study," U.S. Army Corps of Engineers, Philadelphia, Pa., June, 1973.

Table 7.—Projected vessel characteristics 1970 to 2000

	1970	1980	1990	2000
Freighters				
Maximum DWT in world fleet	25,500	33,500	43,500	50,000
Length (feet)	850	930	1,010	1,050
Beam (feet)	108	117	127	132
Depth (feet)	74	80	85	88
Draft (feet)	36	39	40	40
Average DWT in world fleet	8,168	8,853	9,043	9,350
Bulk Carriers				
Maximum DWT in world fleet	105,000	185,000	317,000	400,000
Length (feet)	870	1,040	1,230	1,325
Beam (feet)	125	152	183	198
Depth (feet)	71	84	99	106
Draft (feet)	48	57	66	71
Average DWT in world fleet	14,750	18,750	23,575	27,350
Tankers				
Maximum DWT in world fleet	300,000	760,000	1,000,000	1,000,000
Length (feet)	1,135	1,460	1,570	1,570
Beam (feet)	186	252	276	276
Depth (feet)	94	129	142	142
Draft (feet)	72	98	264	104
Average DWT in world fleet	39,825	76,225	94,325	94,325

Source: Science and Environment, Vol. 1, Panel Reports of the Commission on Marine Science, Engineering and Resources

Table 8.—Summary of federal investments in coastal harbors, 1824-1966 (in thousands of dollars)

	Construction Expenditures	Maintenance Expenditures	Total Expenditures	Non-Federal Cost[1]
Depth: 30 feet and over				
Atlantic coast	420,910	406,275	827,085	29,624
Gulf coast	181,593	122,596	304,189	29,844
Pacific coast	127,684	128,363	256,047	38,227
Subtotal	731,519	657,314	1,388,833	97,695
Related Investments[2]				
Atlantic coast	23,147	5,665	28,812	2,579
Gulf coast	12,065	6,387	18,452	3,609
Pacific coast	32,483	23,723	56,206	14,215
Subtotal	79,402	49,958	129,360	20,479

[1] Monetary value of local contribution identified in project authorization documents.
[2] Additional federal construction items required to sustain functional utility of projects, but not incorporated in basic project.
Source: Science and Environment, Vol. I.

The most obvious environmental effect of dredging is the destruction of bottom-dwelling organisms and habitat. All other factors being equal, the same kinds of organisms will repopulate the new bottom so long as the substrate is the same as that of the original bottom. If the material being dredged contains silt or clay, a "plume" of turbid water will drift down current from the dredging operation. In extreme cases, the turbid water can cause clogging of the gills or filtering apparatus of marine organisms and/or smothering of bottom living organisms under a blanket of deposited materials.

Other potentially serious effects of dredging include changes in water circulation patterns (tidal exchange, flushing rate, stratification, et cetera).

Effects of Disposal of Dredged Material

If the material dredged for the channel consists mostly of sand and/or gravel it is usually referred to as "fill" and is suitable as a core for a breakwater or an artificial island. On the other hand, if the material is silt or clay it is referred to as "spoil" and is a problem to dispose of without potential environmental effects.

The worst possible environmental conditions for spoil disposal would probably be similar to those encountered in a dredging operation in northern Chesapeake Bay. The material to be spoiled was all silt and clay, was hydraulically dredged, and was dumped on a submerged disposal area. Even though the end of the discharge pipe was directed downward, a large plume of suspended sediment moved down current from the discharge point. The disposal area did not contain the deposited sediment within its limits. The spoil apparently spread as a semi-liquid across the relatively flat bottom, covering a larger area than outlined as the disposal site. The character of semi-liquid silt and clay is such that maximum slopes measured are 1:100 (on a flat bottom, a pile of spoil built to a height of 1 ft. will spread at least 100 ft. horizontally in all directions) and average slopes are 1:500.

Biological effects observed in the Chesapeake disposal operation were not severe. The bottom dwelling organisms in the spoil receiving area were wiped out but new populations quickly reinvaded the spoil. It was found that some seasons of the year have less potential for damage both because organisms are less active and/or migrate from the region. If silt and clay are anticipated in the dredging operation, then methods of dredging and sites and seasons of disposal should be chosen to minimize biological effects. As a generalization, silt and clay are less likely to be encountered at port locations on the shelf than at locations inside the estuary. Estuarine silts also have a higher probability of being polluted with materials transported from the upper estuary.

Effects of Construction of Breakwaters or Islands

These structures remove from productivity the bottom environment beneath them. However, riprap or other protective materials surrounding islands and breakwaters create new habitat for marine organisms. So long as these structures are not built on ecologically "rich" bottom, the new habitat created probably represents a neutral or beneficial effect on the biota.

Breakwaters and artificial islands undoubtedly cause changes in the current and wave patterns in nearby areas. These structures can disperse or focus wave energy on nearby coasts, or by changing current velocities, can cause erosion or deposition of sediments with associated effects on bottom living organisms. Breakwater and island design must consider the ecological effects of altered current or wave patterns.

HEAT

Table 9 illustrates the use of cooling water by U.S. industry.

One of the major reasons why temperature is so biologically important is that the rates of chemical reactions are temperature-dependent. Since biological processes are ultimately controlled by the rates of enzyme-regulated reactions, it is not surprising that digestion, circulation, respiration, and reproduc-

Table 9.—Use of cooling water by U.S. industry

Industry	Cooling Water Intake (billions of gallons)	Percent of Total
Electric power	40,680	81.3
Primary metals	3,387	6.8
Chemical and allied products	3,120	6.2
Petroleum and coal products	1,212	2.4
Paper and allied products	607	1.2
Food and kindred products	392	0.8
Machinery	164	.3
Rubber and plastics	128	.3
Transportation equipment	102	.2
All others	273	.5
Total	50,065	100.0

Source: Federal Water Pollution Control Administration, "Industrial Waste Guide on Thermal Pollution," September 1968.

tion increase with rising temperature. In fact, it has been noted that in the vicinity of power plants which discharge heated effluents into temperate waters, many species will reproduce earlier in the spring and continue to produce larvae later into the fall than species in the ambient water. The use of cooling towers and cooling ponds, although more expensive, is replacing once-through cooling with discharge to the estuary.

An innovative concept has been the proposal to construct floating nuclear power plants. All of these plants would be uniform in construction (present ground based plants are custom made) providing less difficulty in licensing procedures, and, presumably, cost savings by production line construction techniques. The construction of a sea defense system (breakwater) to protect the plant from storms and ship collisions is very costly, though. Perhaps such plants, built at remote sites and placed in coastal lagoons using the barrier island as a natural breakwater and cold seawater as a cooling medium would be economically attractive and environmentally acceptable.

Addition of Substances Harmful to Estuarine Organisms

Oil spills in United States waters and documented by the Coast Guard are presented in Table 10. Bulk storage facilities account for almost twice as much spilled oil as the next highest contributor, offshore wells.

Major spills on water are difficult to control and can cause great environmental damage, especially if they reach beaches or marshes. The least harmful spill is one that never occurs. Terminal location and design should be such as to minimize the possibilities of a spill. The less handling that the crude oil receives, the less likely the chances of a spill. For instance, a transfer operation involving pumping from tankers to offshore tanks to lighters to refineries requires three handlings while pumping from tankers to pipelines to refineries involves only two.

Given that, sooner or later, a spill will occur during the operation of a terminal, then containment and recovery operations should begin immediately. Their success depends on the size of the spill, the availability of personnel and equipment, and wind and sea conditions. The closer that a terminal lies to shore, the more rapid must be the response to prevent contamination of coastal margins. In an environmental sense, then, there is greater risk of shoreline contamination if a port is located within an estuary or near the coast.

Organic wastes resulting from industrial processes include compounds that have a high biological oxygen demand (BOD), which cause a reduction in the levels of dissolved oxygen in the receiving waters. The food processing, textile, refining and petrochemical industries all contribute significant quantities of BOD to the environment. The 1974 National Water Quality Inventory showed a decrease in the BOD on 74 percent of the major waterways on which water quality trends have been measured. Industries most often control BOD of effluent waters by secondary sewage treatment. Such secondary treatment can reduce BOD levels by 80–90 percent but produce about 0.75 lbs. of sludge per pound of BOD reduction. A problem then involves disposal of the sludge. Significant progress is being made in the reduction of BOD, phenol and ammonia discharges from refineries.

Table 10.—Polluting spills in U.S. waters—1970

Source	Incidents	Gallons Spilled (millions)	Percent of Total
Spills in excess of 10,000 gals.			
Bulk Storage Facilities	9	6.676	43.5
Offshore Wells	4	3.553	22.8
Pipelines	14	1.316	8.4
Barges	19	1.238	8.0
Transfer Operations	8	1.021	6.5
Dumping	1	.500	3.2
Industrial Accidents	5	.367	2.3

Source: U.S. Coast Guard.

Organic wastes from petrochemical, crude oil handling, and refinery effluents may be toxic to aquatic organisms.

Trace metal concentrations, first publicized by the levels of mercury in swordfish, have come under close scrutiny. The major industrial sources of these metals are chemical, metal refining and metal processing effluents. Toxicity levels of some of these metals to estuarine organisms are presented in Table 11. Trace metal levels may be low in effluents but quite toxic to organisms in receiving waters. They are difficult and expensive to remove.

Health Hazards

Industrial effluents are not major sources of most human pathogens regarded as health hazards. Depending on the particular area, though, industrial effluents may serve as the source of toxic concentrations of trace metals concentrated in organisms which are consumed by man.

Concentration by biological processes is a phenomenon which is readily demonstrable. It is through biological concentration that toxic metals find their

Table 11.—Toxicity levels of metals for several marine organisms (in ppm of dosage)

Metal	Organism Tested	Lethal Level	Time
Cadmium	Eastern Oyster	0.10	15 Weeks at 20°C
	Eastern Oyster	0.20	8 Weeks at 20°C
Chromium	Eastern Oyster	0.102	—
	Nereis sp.	2–10	2–3 Weeks
	Shore Crab	50.0	12 Days
	Small Shrimp	10–40	1 Week, 100%
Copper	Soft Shell Clam	0.50	3 Days at 10°C
	Soft Shell Clam	0.20	23 Days at 10°C
	Soft Shell Clam	0.20	8 Days at 20°C
	Soft Shell Clam	0.10	10 Days at 20°C
	Mussels	0.05	10 Days at 20°C
	Mussels	0.025	24 Days at 20°C
	Nereis sp.	1.5	2–3 Days
	Nereis sp.	0.5	4 Days
Mercury	Five Marine Phytoplankton	0.006	10 Days
Nickel	Eastern Oyster	0.121	—
Lead	Eastern Oyster	0.50	12 Weeks

Table 12.—United States Public Health Service 1968 interim standards for shellfish, in ppm of wet tissue weight. Numbers in parenthesis represent average levels in organisms from Atlantic Coast (after Pringle, 1968)

Metal	Eastern Oyster	Soft Shell Clam	Northern Quahaug
Zinc	1500.0 (1428.0)	50.0 (17.0)	50.0 (20.6)
Copper	100.0 (91.5)	15.0 (5.8)	15.0 (2.6)
Cadmium	0.2 (3.1)	0.2 (0.27)	0.2 (0.19)
Lead	0.2 (0.47)	0.2 (0.70)	0.2 (0.52)
Mercury	0.2	0.2	0.2
Cadmium, Lead, Chromium and Mercury Combined	2.0	—	—

way into the food web. As an example, let us look at phytoplankton, the root of the marine food web. One thousand pounds of phytoplankton support in the food web the following:

100 pounds of zooplankton or shellfish
50 pounds of small food fish (anchovies)
10 pounds of small carnivores
1 pound of carnivores harvested by man
(Council on Environmental Quality, 1971)

Each level in the food web results in the concentration of at least some of the heavy metals concentrated in the previous levels. In addition, at any point in this food web, biological concentration may occur by uptake directly from the surrounding water, thereby further enriching metal concentration levels. Table 12 illustrates the interim standards for acceptable concentrations of metals in shellfish compared with the average levels found in Atlantic coast organisms.

SUMMARY

The technology is available to curb most industrial water wastes. Much has been done, by treatment and by designing production processes that minimize waste. More efficient production processes save money and may improve product quality. Where improved production processes are not available or are not economically feasible, treatment processes usually exist. Their total estimated costs, as a percentage of gross sales, are well under 1 percent, although costs may be much higher for some industries.

Our major industries are easily identifiable and the effluents that they discharge are subject to close scrutiny. In 1968, though, 45 percent of the municipal waste treatment water came from industrial sources. These can prove very difficult to monitor, particularly in our older metropolitan areas. We are just now beginning to quantify and categorize the pollutant sources to the estuary.

The greatest difficulties still to be solved involve the effects of industrial activity on the biology of estuaries. Decision makers need answers to questions like "How much marsh can be filled without significantly affecting the estuary?" and "Where is the 'best' place to locate the next power plant and to dispose of 1,000,000 cubic yards of spoil?" The estuarine system including its organisms, is sufficiently variable in time and space that several years (3–5) are required to get adequate data on the major components of the area. Only in the last decade have we learned enough about estuarine organisms' nutritional and environmental requirements to allow the consideration of controlled environmental laboratories. Results will not come quickly from these labs, but they seem to be the real hope for understanding the effects of environmental perturbations.

By lacking a national policy, we are continuing to encourage industrial development in the estuaries, particularly those areas which are already stressed. Let's look at an example, the refining industry. As has been mentioned, refineries (at least east coast refineries) have been established at most of our ports. A number of new refineries have been proposed but abandoned, usually on environmental grounds. Clearly, the proposal to establish a refinery indicates

that a market exists for the products. But if the refinery isn't built, where does the product come from? Existing refineries, located on stressed estuaries, expand to increase production. We need a strong national policy to help "noxious but necessary" industries to find new locations. Offshore industrial islands (out of state jurisdiction) whose effluents must meet water quality standards may be an alternative to continued development in ecologically stressed estuaries. Agencies of the federal government have been quite innovative and responsive in dealing with water quality problems. As an example, the EPA developed "Criteria for Determining the Acceptability of Dredged Spoil Disposal to the Nation's Waters." The criteria are strict, and a number of dredging projects, particularly estuarine projects, could not pass the EPA criteria. The Corps of Engineers was responsive to the EPA criteria and launched a 5-year, $30 million "program of research . . . to develop the widest possible choice of technically satisfactory, environmentally compatible, and economically feasible disposal practices."

Inherent in the above case of cooperation is that dredging of channels to the ports located at the head of the estuary will continue indefinitely. The question that has been posed seems to be "How can we reduce the impact of industrial pollution in our estuaries by adopting water quality standards and/or allotments?" Federal policy seems to be responsive to that most important question.

I submit that there is another, longer-term but equally important question that may not have yet been asked and certainly has not yet been answered. It is "How can we reduce the impact of industrial pollution in our estuaries by assisting industrial centers dependent on water transportation, located on estuaries which are not deep enough to handle modern ships, are not large enough to assimilate wastes, and which are incredibly valuable as a biological-recreational natural resource, to find new, more environmentally acceptable sites?"

Regional groups must initiate work on the identification of the areas, in an environmental sense, that can better accept the industrial wastes now discharged into our estuaries. The National Coastal Zone Management Act (16 USC, Sec. 145-1464) may serve as an excellent vehicle to achieve this long-term objective.

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INDUSTRIAL WASTE POLLUTION AND GULF COAST ESTUARIES

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ABSTRACT

The status of gulf coast estuaries is explored with regard to degradation of water quality from a variety of sources and mechanisms, emphasizing industrial waste effluents. The typical features of gulf coast estuaries, particularly the limited tidal action, the presence of bays behind barrier islands, and in many cases, limited flushing, are outlined.

Environmental modification as differentiated from environmental pollution is presented and examples of the impact of each on Texas gulf coast estuaries is discussed. A hierarchy of water quality problems is presented and used to document the principal water quality problems in seven selected Texas estuaries. The causes of the degradation which lowers water quality in these seven estuaries are listed with emphasis on waste-generating industries.

The Houston ship channel is used as a case study to outline the potential solutions to each of the individual water quality problems. A plea is voiced for the consideration of novel or innovative solutions to water quality problems such as the concept of supplemental aeration which is proposed for the Houston ship channel.

INTRODUCTION

This presentation will explore the status of gulf coast estuaries with regard to degradation of water quality from a variety of sources and mechanisms with emphasis on the role of industrial waste effluents. Since the author's major work has centered on the gulf coast of Texas, the greatest attention will be directed at these estuaries as typical of the gulf coast area. A map of the Texas gulf coast is shown as Figure 1.

TYPICAL GULF COAST ESTUARIES

The major feature that differentiates gulf coast estuaries from those on the east and west coasts is the limited tidal range found along the gulf. This phenomenon is demonstrated in Figure 2 where it may be noted that the tidal pattern for several gulf coast estuaries follows a pattern from diurnal to semidiurnal with a range of only one to two feet.

The most significant gulf coast estuaries have large, shallow bays, separated from the Gulf of Mexico by barrier islands. These typically have one or more major rivers entering their landward ends which bring freshwater into the system. In the Texas gulf, the inflows to the major estuaries west of the Neches River are often small, leading to relatively slow flushings of the estuaries. For example, the upper Houston ship channel has an average flushing time of 38 days and a flushing time as great as 80 days over 10 percent of the time. The median flushing period for the ship channel above Morgan's Point is 30 days and that for Galveston Bay is 175 days.

This combination of limited tidal mixing and limited freshwater inflow creates a condition which is particularly susceptible to the buildup of pollutants and, consequently, to a significant impact of these pollutants in the water quality.

In the deeper estuaries or in dredged channels, gulf coast systems are partially stratified with lighter, less saline water overriding a more saline deeper layer. The degree of salinity difference varies from day to day as a function of freshwater inflow and turbulence generated by tides, wind, ship traffic, and other forces.

In the shallow bays and the deeper systems after extensive mixing, the salinity in the top and bottom layers is the same, creating what is defined as a homogeneous estuary. Evaluation of the impact of man's activities on estuaries requires a thorough understanding of the movement of water masses and pollutants in these systems.

ENVIRONMENTAL MODIFICATION

Gulf coast estuaries as they existed in the 19th century have been exposed to a wide range of environmental modification, as well as environmental

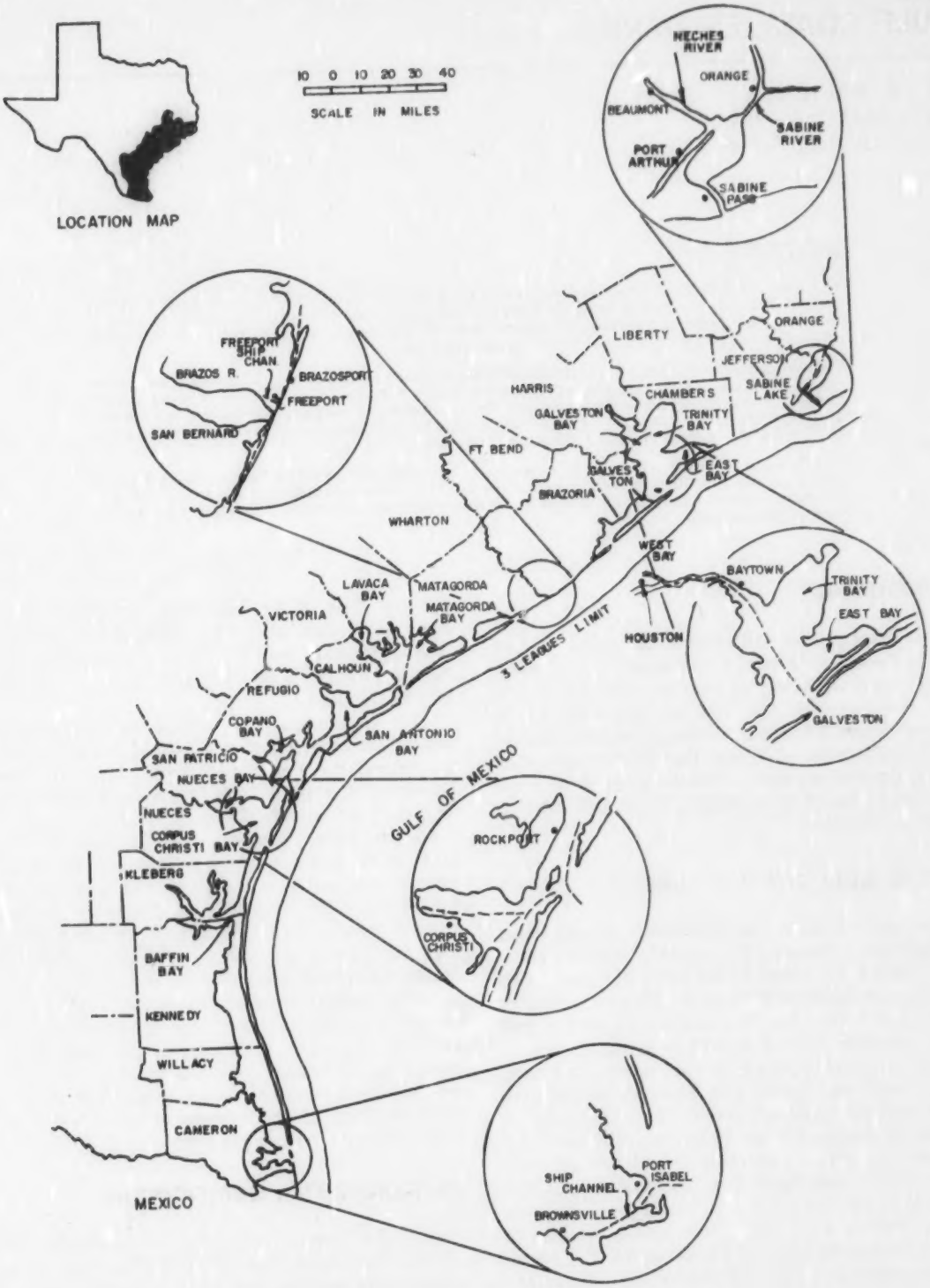

FIGURE 1.—Texas coastline.

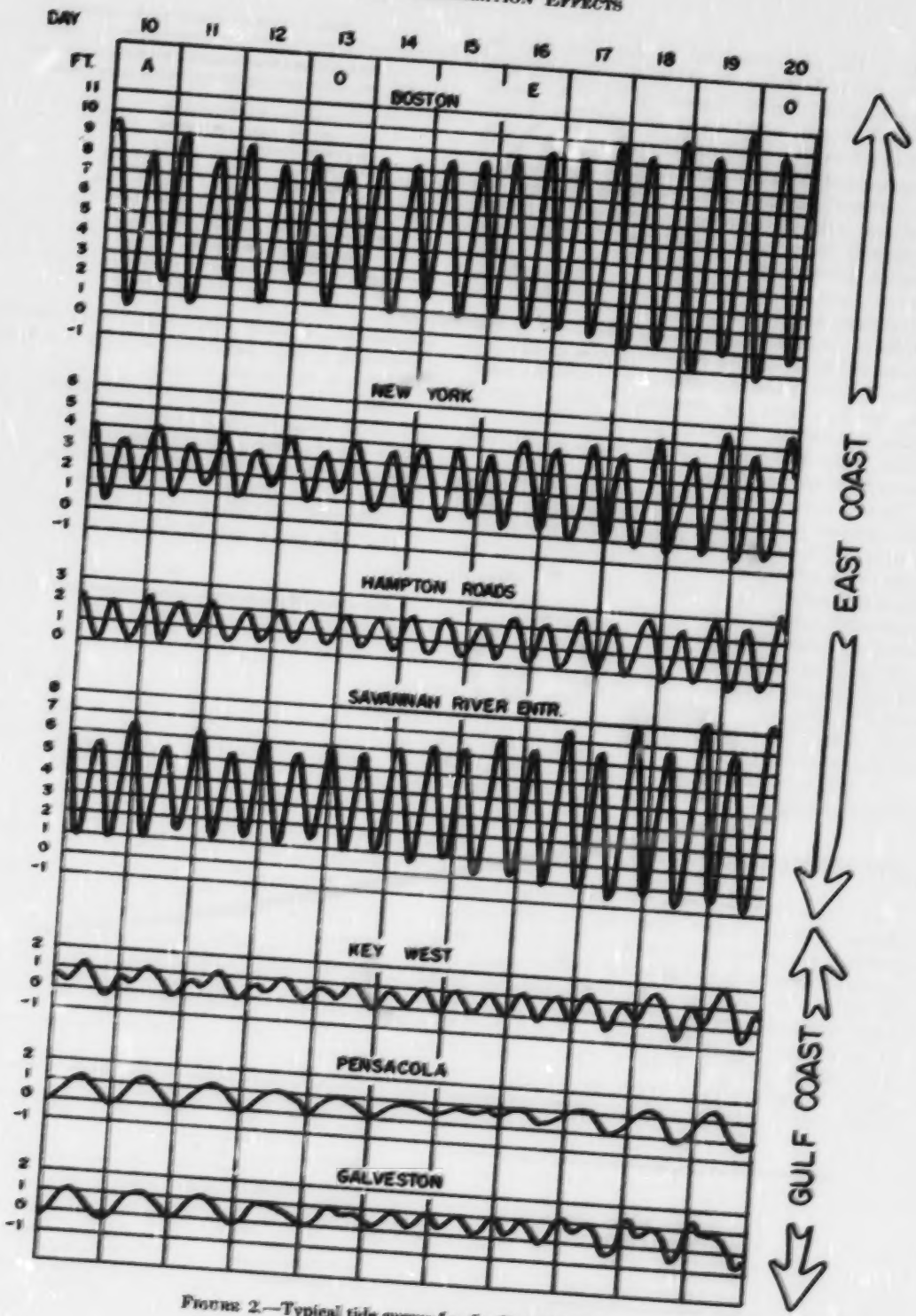

FIGURE 2.—Typical tide curves for the United States.

pollution. The environmental modification may be described in this context as changes in the physical, chemical and biological characteristics of a system as a result of engineered works and changes in land use. Environmental modification may result in both environmental costs and benefits.

In contrast, environmental pollution involves the direct and indirect discharge of pollutant materials as effluents from man's activities. Environmental pollution predominantly results in environmental costs or degradation with only occasional environmental benefits being demonstrated.

A list of the most important environmental modifications which affect gulf coast estuaries is shown in Table 1. The most significant of these in many estuaries has been the dredging of ship channels across shallow bay systems and river channels to higher, more protected land as much as 50 miles inland from the coastline.

These channels have changed estuarine flushing and circulation patterns and altered their salinity structure. The upstream modification of the river systems by reservoirs and other structures has also drastically altered the estuarine systems by affecting freshwater inflows, altering salinity structure, and reducing sediment and nutrient inflows.

These environmental modifications have wrought substantial and continual changes in these estuarine systems, generally making them more useful to man. They have also created the physical and economic climate in which cities, industry, and commerce have flourished and have brought the spectre of environmental pollution to our estuaries.

ENVIRONMENTAL POLLUTION

Environmental pollution is defined as the discharge of man's waste products into the environment. A convenient mechanism to consider environmental pollution is to follow an outline which may be called the "Hierarchy of Water Quality Problems" and assess the applicability of each parameter at it relates to the estuarine environment. This hierarchy is shown in Table 2. The ordering of the initial items generally conforms to the order in which water quality problems were perceived in freshwater streams. However, with our present technology, any parameter can be the dominant problem in any given estuary.

Table 3 examines the relative significance of each of these parameters in selected Texas gulf coast estuaries. For each estuary, the relative significance has been rated as H (highly significant, i.e. major problem), M (moderately significant), L (slightly significant), and Blank (no known problem). Additional categories are N for not known and P to

Table 1.—Environmental modifications affecting Texas estuaries.

1. Ship Channels
2. Upstream Water Resource Development
3. Water Withdrawals and Returns
4. Drainage of Marshlands
5. Urbanization
6. Sand, Gravel and Shell Dredging
7. Dikes, Jetties and other Structures

Table 2.—Hierarchy of water quality problems.

Pathogenic Bacteria and Related Coliform Indicating Organisms
Oxygen Demanding Organics and Resulting Oxygen Depletion
Inorganic Ions
Nutrients and Resulting Eutrophication
Sediments: Both Organic and Inorganic
Temperature Changes
Heavy Metals
Radionuclides
Pesticides and Herbicides
Refractory Organics
Oil Pollution
Hazardous Polluting Substances

Table 3.—Hierarchy of water quality problems related to selected Texas estuaries

	Houston Ship Channel	Houston Ship Channel	Galveston Bay	Brazos River	Corpus Christi Ship Channel (Inner Harbor)	Corpus Christi Bay	Brownsville Ship Channel
Pathogens	L	H	H		H		
Oxygen Demanding Organics	H	H	L	L	M		L
Nutrients	M	M	L		L	L	
Sediments	M	M	L	M	L	L	
Temperature	L		M	L		L	
Heavy Metals	M	H	L	M	H	M	
Radionuclides		H					
Pesticides & Herbicides	L	L	L	L			
Refractory Organics	M	H	M	L	L		
Inorganic Ions				M			
Oil Pollution	L-P	M-P	P		M-P	P	P
Hazardous Polluting Substances	P	P	P	P	P	P	P

H—Major Problem
M—Moderate Problem
L—Slight Problem
Blank—no problem at this time
N—Not Known
P—Potential for Major Problem from Spill Situation

Table 4.—Pollution sources for selected Texas estuaries

	Neches Ship Channel	Houston Ship Channel	Galveston Bay	Brazos River	Corpus Christi Ship Channel (Inner Harbor)	Corpus Christi Bay	Brownsville Ship Channel
Domestic Sewage	L	H	L	H	L		
Urban Runoff	L	H	L		L		
Agricultural Runoff	L		L	L		L	
Petrochemical Industry	H	H	H	L	H	L	L
Petroleum Refining	H	H	M		H	L	
Pulp and Paper	H	H	L				
Mining	H		L				
Metal Processing	L	H	L	H	H	H	
Fertilizer		H	L				
Power Generation	H	L	H		L	L	
Dredging of Virgin Mtls.			M			M	
Maintenance Dredging	H	H	M	M	H	H	L
Marine Commerce	L-P	L-P	P	P	P	L-P	P

H—Major Waste Source
M—Moderate Waste Source
L—Minor Waste Source
Blank—No Significant Waste
P—Potential for Major Problem from Spill Situation

indicate a potential problem exists, but is not a chronic situation.

Table 4 carries the analysis further to identify the sources of the pollution by class in each estuary. Each of these estuaries, its individual problems and status will be discussed in following sections.

SELECTED TEXAS ESTUARIES

Seven Texas estuarine systems were selected for consideration in this presentation. The ones chosen span the Texas coast from the Neches estuary near the Louisiana border to Brownsville, the southernmost ship channel-estuary only a few miles from the Rio Grande River border with Mexico. The unique features of the individual estuaries and the role that industrial waste pollution plays in the overall water quality problem will be discussed.

The Neches Estuary

The Neches Estuary has its beginning at the confluent of the Neches and Sabine Rivers, some 20–30 miles inland from the Gulf of Mexico. This report is concerned with the lower 23 miles of the estuary (up to Beaumont, Tex.), which has been dredged for deep draft navigation. Saline water penetration above this point will in the future be prevented by a salt water barrier.

Since the city of Beaumont diverts its domestic sewage to Taylors Bayou which does not enter the Neches Estuary, very little domestic waste reaches this estuary. Similarly, urban runoff loads are not a major impact. Thus, for all practical purposes, the Neches Estuary pollution problems result solely from wastes discharged by the industries which line its banks. These include a pulp and paper plant, a sulphur mining operation, a metal processing plant, two fossil fuel electrical generation plants, and almost a dozen refinery and petrochemical plants and related shipping terminals.

The development of these industries during the 1950's and 1960's led to a grossly overloaded condition with regard to the water quality of the Neches River. A study carried out by the author in 1969 indicated that a freshwater inflow of over 5,000 cubic feet per second would have been necessary to achieve the stated water quality standard for dissolved oxygen of 3.0 mg/l. Consistent flows anywhere near this figure are not possible from the Neches River system, particularly as most if not all of the summer freshwater flow is diverted from the river for domestic use and irrigated farming.

An initially aggressive program to reduce the then-loading of 278,000 lbs. of BOD inflow per day was begun in 1970, but was delayed to investigate regional waste treatment. Since that time, the stream standards have been drastically lowered to require only 2.5 mg/l dissolved oxygen one foot below the water surface at a flow of 1000 cfs. These standards are questionable because roughly 25 percent of the time periods of flows below 1000 cfs are expected in the Neches and the one foot below the surface sampling location is not considered adequately representative.

The target waste loadings specified by the Texas Water Quality Board call for waste load reductions by 1977 to 20,400 lbs/day of ultimate oxygen demanding wastes above River Mile 11 and 26,187 lbs/day for the entire estuary. If these targets are achieved along with similar reduction of heavy metals and other contaminants, substantial improvement should be realized.

Further improvement could involve either further treatment, supplemental aeration, or diversion of the cooling water discharge from the Gulf States Power Generation Station to the upper estuary in order to assure a minimal flow throughout the estuary.

The Houston Ship Channel

The city of Houston has achieved the distinction of becoming the third largest port in the nation even though it is located some 50 miles from the coastline. Houston is connected to the Gulf of Mexico by a dredged deepwater channel across 25 miles of the otherwise shallow Galveston Bay and then, another 25 miles upstream from Morgan's Point, up what was once the lower reaches of the San Jacinto River and Buffalo Bayou to its terminus at the turning basin near downtown Houston.

This deep draft channel is the major lifeline of the city of Houston and it is along the upper 25 mile stretch of the channel that the major industries of the Houston industrial complex are located. The dominant industries, of course, are petroleum refining and petrochemical production, but others found along the channel include: pulp and paper, metal processing, fertilizer, power, cement, grain elevators, and manufacturers of offshore oil field structures. Warehouses and tank terminals also serve the area's marine commerce. By 1969, the waste loading from this industrial complex coupled with the domestic waste effluents and urban runoff reached, after treatment, the loading of over 500,000 lbs/day of ultimate oxygen demand. Almost all the other pollutants discussed earlier as part of the hierarchy of water quality problems were also discharged in large amounts. The BOD ultimate load overtaxed the allowable loading of 20–25,000 lbs/day as determined by mathematical modeling by a factor of between 20 and 25 to 1.

During this time the waters in the upper 16 miles of the channel were completely depleted of oxygen in every month of the year, black anaerobic sludges were building up on the bottom at the rate of 2–5 feet per year from sediment and organic waste discharge and the waters were so bacterially polluted that one gallon of ship channel turning basin water added to a 20,000 gallon swimming pool would cause it to be unacceptable from coliform bacteria count standards.

The industrial waste loadings to the channel have been reduced dramatically. Whereas in 1969, two-thirds of the loading excluding urban runoff was due to industry, now only one-third is industry related, according to Texas Water Quality Board figures.

The domestic waste of the city of Houston now is the major biodegradable organic pollutant load. In addition to heavy overloads by infiltration, the city still discharges large quantities of digested sludge into the channel.

During periods of high runoff from Houston, it is estimated that the urban runoff pollution loading equals or exceeds the domestic waste loading thus making it the dominant biodegradable pollution. The urban runoff also brings nutrients, sediments, and heavy metals into the channel.

The author has argued that specific pollutants such as heavy metals, unusual nutrient loads, oil and hazardous materials, and so forth must be reduced at each individual source and precautions taken to insure against major shock loads from spills and plant upsets. He has also argued that organic waste loading, being common to all polluters, is a problem susceptible to a novel cooperative solution. This Houston ship channel problem and the options for solution are discussed in greater depth in a later section.

Galveston Bay

Galveston Bay is the largest bay on the Texas gulf coast and considered to be most productive, both economically and ecologically. The bay is approximately 520 square miles in surface area. The major freshwater source is the Trinity River which drains central Texas, including the Dallas-Fort Worth area. Other sources include the San Jacinto River, Buffalo Bayou, Clear Creek, and other small creeks and bayous.

The bay is generally believed to be of good quality with the exception of coliform bacterial pollution and the unknown effect of refractory organics discharged by the Houston ship channel complex, and thermal discharges. The major pollution sources which impact on the bay and the major environmental modifications to the bay system are listed in Table 5. The solution to the pollution problems of this important bay is that of insuring that each of its inputs is of acceptable quality.

The impact of environmental modification will probably be of more importance to the bay in the future than environmental pollution.

Brazos River

The Brazos River differs from the other estuarine systems in that the river runs directly into the Gulf of Mexico without having a large bay at its mouth. The Brazos River has the largest drainage area in Texas and is partially controlled by upstream rivers. Flows range from near zero to major floods. Natural freshwater quality is affected by salt spring discharge and agricultural runoff. The major industrial discharges consist of saline waste streams from seawater processing, and petrochemical production wastes from several plants of a single company,

Table 5.—Environmental pollution and environmental modification of Galveston Bay

Significant Pollution Sources
1. Houston Ship Channel
2. Bayport Industrial Complex
3. Texas City Industrial Complex
4. Trinity River Inflow
5. Galveston Ship Channel and City of Galveston
6. Power Plant Discharges
7. Clear Lake Drainage Area
Significant Environmental Modification
1. Houston Ship Channel and Associated Dredge Spoil
2. Galveston, Texas City, Bayport and Cedar Bayou Channels and Associated Dredge Spoil
3. Upstream Water Resource Development on the Trinity River Including the Wallisville Reservoir
4. The Water Diversion from Tabbs Bay and the Houston Ship Channel as Part of the Cedar Bayou Power Generation Station
5. Upstream Water Resource Development on the San Jacinto River
6. Land Subsidence by Excessive Ground Water Production Centered Around the Upper Houston Ship Channel
7. Urban Development and Associated Runoff Characteristic Changes Around the Bay
8. Various Dikes, Jetties, Fish Passes and Other Structures

discharged a few miles above the river's mouth. The lower reaches of the river also suffer from domestic waste discharges from cities in the Freeport area.

Current plans for the construction of a superport off the Texas coast near Freeport will undoubtedly lead to increased industrial waste loading in the lower portion of the Brazos River.

Corpus Christi and the Corpus Christi Ship Channel

Corpus Christi Bay and its inland companion bay—Nueces Bay, form one of the larger bay systems on the Texas Coast. A ship channel has been dredged across Corpus Christi Bay to the city of Corpus Christi and thence alongside the city for a distance of 8.5 miles. It is this inner harbor which receives the heaviest industrial waste loading and which is included as a separate system for rating purposes. The quality in the inner ship channel is poor with regard to some parameters, but is substantially better than the major ship channels in eastern Texas mentioned previously. The channel is a useful study area to indicate how the Neches and Houston ship channels will behave when their quality improves.

The channel is subject to oil spills from a variety of commercial and industrial sources, and governmental entities have joined to form the most effective Oil Spill Control Cooperative on the Texas coast. This group has cleaned up almost 100 oil spills ranging from a few gallons to 13,000 gallons. This organization is serving as a model to potential groups elsewhere.

Brownsville

The port of Brownsville is a unique estuarine system in Texas. Unlike most other Texas ship channels, the Brownsville shipping channel was not dredged up an existing river. Dredging the Rio Grande would have had international implications as well as involving the sediment and other pollutants of the river. Thus, the channel is entirely manmade for commercial and industrial purposes. The channel is also blessed with good quality water and the governing authority, the port of Brownsville, is carefully programming development to insure maintenance of this quality. Only in Brownsville can one fish successfully in a ship channel turning basin.

TRENDS AND SOLUTIONS

The Houston ship channel is an excellent system to consider with regard to water quality management because the system receives almost all types of pollutants in significant amounts from nearly every class and type of polluter. The upper 25-mile segment of the Houston ship channel is shown in Figure 3. The system is also significant because classical solutions to water quality problems will not achieve required or desired water quality in this system. Thus, innovative techniques which go beyond traditional "dilution is the solution," "treatment at the source," and "classical complete treatment" must be developed.

These include new analysis techniques for exotic pollutants, novel advanced treatment methodology and in situ processes such as supplemental aeration to improve quality. A brief outline of ship channel problems and the appropriate solutions are shown in Table 6.

The problem of oxygen demanding wastes will be discussed in depth as it demonstrates several of the points to be made in this presentation. As mentioned previously, the Houston ship channel in 1969 was receiving a daily loading of over 500,000 lbs. of BOD_u per day. In layman's terms, this is roughly the equivalent of 500,000 lbs. of sugar per day. By 1973, the loading had been reduced to those shown in Figure 4. In 1969, about 60 percent of the problem was industrial wastes, 20 percent domestic wastes, and 20 percent urban runoff. By late 1973, the ratios were more like 45 percent urban runoff, 35 percent domestic wastes, and 20 percent industrial wastes during periods of urban runoff, and 65 percent domestic waste and 35 percent industrial waste during periods of no runoff.

Also plotted on Figure 4 is the value range for the assimilative capacity for oxygen demanding material

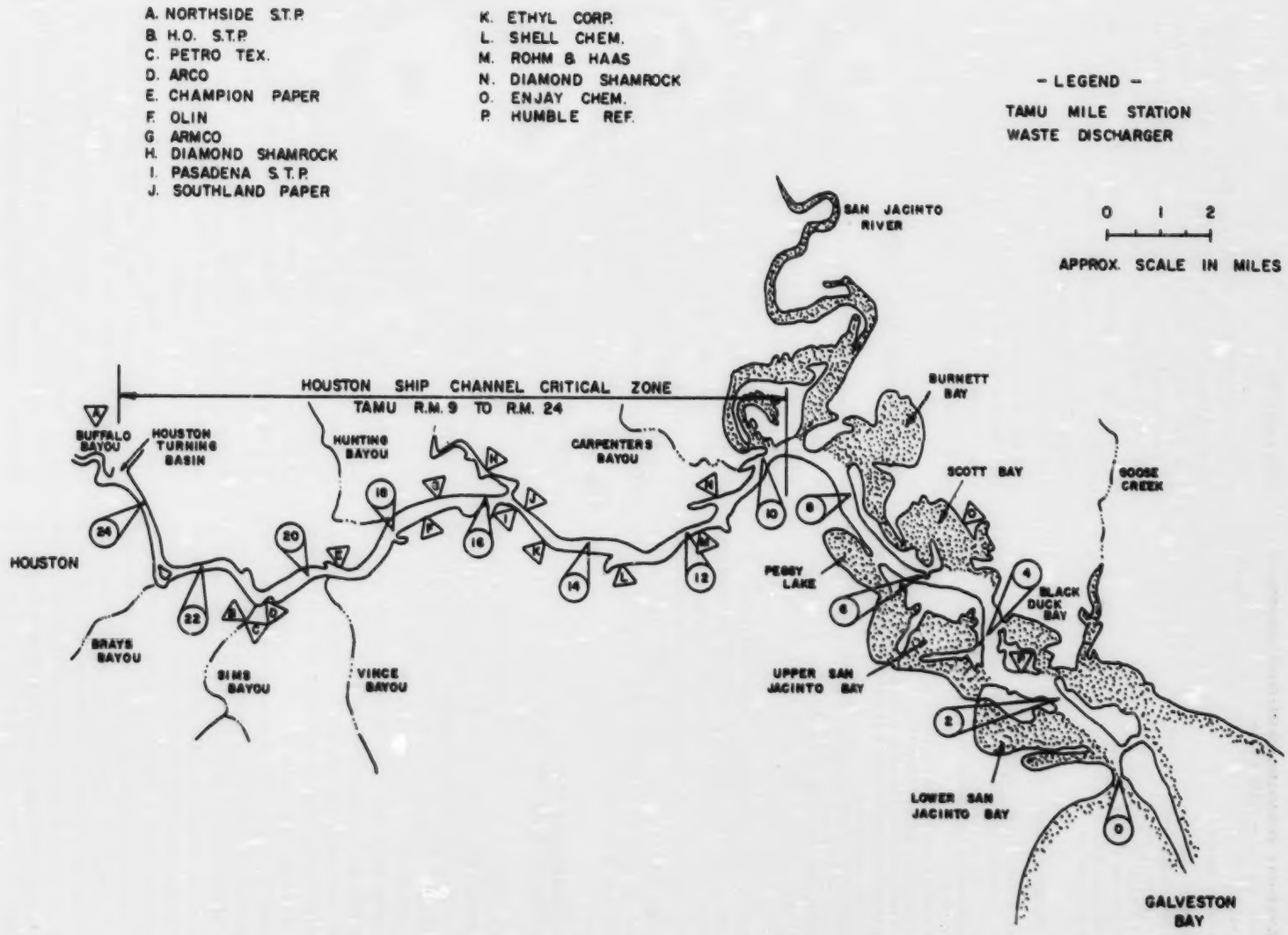

FIGURE 3.—Location of domestic and industrial discharges on the Houston ship channel.

Table 6.—Solution matrix, Houston Ship Channel problems

Problem	Solution
Pathogenic Organisms	Higher level domestic waste treatment, effluent chlorination reduction of sewer infiltration.
Oxygen Demanding Organics (Domestic)	Improved secondary waste treatment, advanced waste treatment and supplemental aeration.
Oxygen Demanding Organics (Urban Runoff)	Supplemental aeration.
Oxygen Demanding Organics	Improved waste treatment and supplemental aeration.
Nutrients	Advanced domestic and selective industrial waste treatment.
Sediments	Better sewage sludge handling and control of sediment from land and highway development.
Temperature	No major solution needed.
Heavy Metals (Industrial)	Process change and selective waste treatment.
Heavy Metals (Domestic)	Elimination of heavy metal discharges to the sewer system and waste treatment plant operation for heavy metal removal.
Heavy Metals (Urban Runoff)	
Refractory Organics	Better identification of pollutants—waste treatment with existing or new treatment processes—little known in some areas.
Oil Pollution	Better preventive action. Contingency planning equipment and training of industry and government personnel.
Hazardous Polluting Substances	Better preventive action. Contingency planning equipment and training of industry and government personnel.

for each month of the year based on federal-state water quality standards for the upper Houston ship channel.

The solution is obvious: namely, the load curve must be below the assimilative capacity curve. The traditional manner is to only reduce the waste loading; however, in this case, the residue waste loads from high level industrial and domestic treatment plus the urban runoff will still overload the system. The current reduced loadings still overload the channel by a ratio which varies from 6:1 without urban runoff to 10:1 during runoff periods. The channel still remains depleted of oxygen in its upper 10 miles during most of the year.

Occasional sitings of marine life in the channel after prolonged high inflow-cool temperature situations, do demonstrate a modest improvment in quality over that found five years ago, but this has been publicized out of proportion to the true situation.

The author has argued that an acceptable interim solution to the Houston ship channel oxygen balance is to increase the assimilative capacity of the system

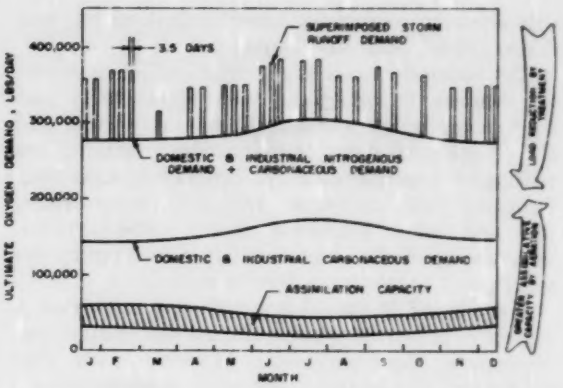

FIGURE 4.—Oxygen demand and assimilation capacity, Houston ship channel, mile 9 to 24 (1972 values).

with supplemental aeration which can be achieved at a very reasonable cost. In addition to its cost effectiveness in terms of social cost and energy efficiency, the proposed system also provides a reserve or fail-safe capacity for shock loads and/or future system loads by new discharges.

The concept is enthusiastically endorsed by the local Gulf Coast Waste Disposal Authority, the waste management entity with the authority to finance, build and operate the system, but acceptance of the concept has been slow on the federal level because of the resistance to novel or innovative solutions to achieve the desired end product of a cleaner environment.

Surely, more objective consideration can be given in the future—particularly, when it is realized on the national level that the goal of zero pollutant discharge is unachievable and that alternate technology which protects the environment must be sought.

SUMMARY AND CONCLUSIONS

The author has presented the unique factors concerning gulf coast estuaries which must be considered in managing these systems. Foremost are tide range, geometry inflow varieties, and density structure. These parameters make their behavior quite different from most east and west coast estuaries. Environmental modifications within and without the estuarine system which will continue to bring about change in the physical, chemical and biological characteristics of these estuaries in the absence of waste loadings are reviewed. They include ship channels, upstream water resource developments, water withdrawals and returns, drainage,

urbanization, sand, gravel and shell dredging, and dikes, jetties, and other structures.

The classical hierarchy of water quality problems is examined to determine their applicability and importance in the gulf coastal zone in general and the Texas gulf coast in particular. Included are pathogenic organisms, oxygen-demanding organisms, inorganic ions, nutrients, sediments, temperature, oils and other floatables, heavy metals, radionuclides, pesticides and herbicides, refractory organics, and hazardous polluting substances.

For several of the Texas gulf coast estuaries, a matrix is presented which outlines the relative significance of these parameters in each system. This is followed by a matrix which summarizes the source of the pollutants in these selected Texas estuaries. Particular attention is given to industrial waste discharges, with oil refining and petrochemical, pulp and paper, mining and metal processing, fertilizer, and power plants predominating. Particular attention is given to the problems of the Houston ship channel as these display trends and make pertinent points.

Industrial wastes continue to be the dominant pollutant source in many gulf coast estuaries and a significant loading in others. Industrial attitudes toward pollution control still range from public spirited companies who lead the way in pollution control to those few bad actors who resist and avoid any major commitment toward pollution control until dragged to the courtroom.

Industry as a whole, however, has generally proved receptive to carrying its load when it has been effectively demonstrated that a problem really exists and that a true solution will be achieved by the steps they have been asked to carry out and the costs they are expected to bear. All too often, however, an individual industry has been asked to clean up when his counterparts have not. This is particularly evident in the Houston ship channel, where some industries have had effective treatment programs for almost a decade while some foot-dragging industries and the city of Houston have lagged far behind in cleaning up their effluents.

Even the most responsible industry personnel have doubts as to the need and economic justification of some of the requirements they are being asked to meet—particularly, toward the goal of zero pollution discharge.

It is validly argued that policy must be more closely tailored to individual situations and to the social costs and energy resource situations which exist today.

With these thoughts in mind, the following list of recommendations is formulated for consideration for the country as a whole and particularly, for consideration for gulf coast estuaries.

RECOMMENDATIONS

1. Programs to reduce industrial waste discharges should be continued. We still have a long way to go with some industrial discharges to achieve even basic levels of treatment.

2. Additional programs to characterize wastes and their impact should be carried out. There are still wastes that are not characterized and for which environmental impact is unknown.

3. Greater effort should be made to use appropriate parameters in assessing impact and developing management plans.

4. Equal effort should be placed on reducing domestic waste loadings with particular attention given to reducing the industrial wastes discharged into municipal systems.

5. Greater effort should be placed on the problem of urban runoff from cities whose runoff drains into estuaries. This must include erosion control to limit sediments.

6. It must be recognized that every estuary is different and should be evaluated for its unique situation, preferably using local scientists and engineers who understand the system.

7. Policy should permit innovative and unique solutions, i.e. different solutions are appropriate for different estuaries.

8. Solution choices must include consideration of social cost and energy efficiency. Policy must be upgraded to consider the realities of the times.

9. Failsafe systems are necessary to prevent a single plant breakdown from overpowering the effect of expensive control programs.

10. Realistic terms should be used to describe estuary quality or loading as compared to the allowable loadings based on quality standards. For example, claims of modest improvements in Houston ship channel quality, particularly, during high flow periods should not be allowed to hide the fact that the system is still overloaded by a ratio of 10:1.

11. Effective control programs for industrial wastes and domestic wastes should improve the quality of sediments and reduce pollution potential of dredged materials.

12. Enforcement activities to stimulate compliance by the few "bad actors" should be renewed.

13. Expanded activity to identify and control the danger from hazardous chemical substances shipped in marine commerce should be instigated including routine bioassay analysis of hazardous materials shipped in bulk.

14. The quest to determine the true cost of zero pollutant discharge and the accompanying ultimate disposal of residues should be pursued with the goal of achieving reasonable solution of our estuarine problems without generating a backlash which will stop us short of our goals.

15. More attention should be placed on the effect of environmental modification on estuarine ecology.

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POWER PLANT EFFECTS

IMPACT OF WASTE HEAT DISCHARGED TO ESTUARIES WHEN CONSIDERING POWER PLANT SITING

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ABSTRACT

With present experience certain efficiencies can be brought to bear on evaluation of proposed power plant sites. These concern (1) ways and means of determining what data are really needed for thermal discharge impact evaluation, and (2) optimization of efforts to obtain such data.

Data relevance cannot be determined through comparison with a list of parameters which must always be studied at every site, but rather through a list of topics to be considered for possible study, i.e., questions to be asked (the answers to which determine the parameters which need study at the specific site under consideration).

Optimization of data acquisition could be greatly improved through addition of geographic indicators to all environmental data publications and indexing/storage systems, following the examples set by EPA STORET and NODC listings for water quality parameters. Such complete data availability will make possible better predictions of significance of impact, and therefore more realistic and consistent decisions on utilization of our environment.

INTRODUCTION

It is encouraging to see that progress is being made in some quarters toward devoting appropriate effort to evaluating the effects of thermal discharges on the estuarine environment. Now is the time to take advantage of the experience of the past few years, and move into more efficient protection of the environment and more productive utilization of scientist and engineer hours.

The power industry has now docketed some 200 nuclear generating stations, and each of these has required an environmental report—new ones of massive proportions (on the order of 1,500 pages to *summarize* studies). Similar, though generally less massive, environmental impact statements have been filed for new fossil-fueled generating stations.

Certainly in producing these documents considerable independent effort has been oriented toward obtaining data of much similarity. While it is certain that many have long wished for standardized descriptions of environments and environmental impacts, biologists and ecologists have been more modest, perhaps because of their familiarity with environmental complexities. Their wish has been for standardized programs for collection of the data necessary for such descriptions. In fact, that item which is of major concern in this paper is actually composed of two subtopics: first, the seeking of standardized criteria for the amount and kind of data required for any given site, and second, improvements in how such data are acquired.

These then are the two topics which will be addressed in this discussion: (1) ways and means of determining what data are needed for thermal discharge impact evaluation; (2) optimization of efforts to obtain such data.

DETERMINATION OF DATA NEEDS

Obviously, the first question—determination of data needs—has been addressed, consciously or subconsciously by every scientist, engineer, administrator, elected official, and voter confronted with a change in his or her environment. Each of us is either unfortunately vulnerable to bias, or fortunately able to perceive the true picture, due to our own experiences, training, and our career objectives. We may be highly motivated to:

(1) Preserve the environment in its pristine condition;

(2) Make possible most efficient utilization of the earth's resources; or

(3) Take advantage of every opportunity to gain further knowledge of the detailed interactions of all creatures in the complex ecosystems.

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Of course, all of these sometimes diverse intermediate goals are expressed in terms of everyone's final goal of "Betterment of Mankind." Certainly within reasonable limits we should all be striving toward all the above three intermediate goals as well as the final one. But, before we rush to accomplish one and all, we must look to the aforementioned "reasonable limits" as we direct our efforts and resources toward achieving one of the goals, or better, toward some multiple use concept.

Thus, this paper will discuss means of determining the logical responsibility for environmental studies which should be assigned to the power industry, or indeed to any other industry wishing to utilize a portion of our environment.

It is important to note at the very beginning that aquatic ecological surveys and monitoring must be carried out to ensure that impacts of thermal power plants on aquatic communities do not exceed acceptable levels. To formulate these specific protective standards, an integrated overview approach must be set up to identify potential for significant effects upon important organisms at the earliest possible time. Similarly, such a scheme should quickly identify those areas in which limited or no effort is needed. As a step toward providing a framework for such an overview, this presentation will draw upon a draft version of American National Standards Institute's Standard No. N224 "Aquatic ecological surveys required for the siting, design, construction, and operation of thermal power plants." This standard has been drawn up by a committee composed of representatives of utilities, architectural and engineering firms, consultants, universities, private laboratories, and government agencies, including the Environmental Protection Agency, the Nuclear Regulatory Commission, the National Oceanic and Atmospheric Administration, and the Fish and Wildlife Service.

This ANSI draft standard has been constructed on the theory that while no one set of prescribed procedures will permit evaluation of all sites, a uniform set of questions can serve to rank parameters and permit concentration of efforts on those actually worthy of specific studies, for individual sites.

For example, the lower Mississippi River is, in terms of saline distribution, a fairly typical estuary, However, after only a brief investigation, one can see that the river itself has been channelized and confined by levees for many miles, so that it now resembles a smooth walled pipe characterized by high-speed, frequently unidirectional flow. The classical estuarine functions of providing habitats and nursery areas for aquatic organisms, have been fulfilled in this area by the bayous and onshore island/sandbars along the coastline of Louisiana and adjoining states. Thus there is a reversal in the more common rank of the estuary and coastline areas for utilization as sites for energy production. This is not to say that unlimited development should be allowed to take place along the river, but only that overall, the order of thoughtful utilization is somewhat different. Thus one may minimize the potential for a large scale study of possibly non-useful parameters, and find that a more directed study is really needed.

This paper is intended as an aid to, not a substitute for, professional judgement on a case-by-case basis. Designed to promote uniformity and efficiency, this guide will assist those not familiar with some of the complexities of the natural environment. Using it, the executive or engineer may better understand a specific environment's interrelationship with a steam electric generating station.

A survey of environmental regulations, the biological state-of-the-art, and recent power plant license review cases, suggests some general needs for aquatic ecological surveys. These basic needs (Table 1), briefly described in this section, should help shape the general philosophy of thermal impact surveys.

The first need is to recognize the limitations inherent in the current biological/ecological state-of-the-art. Aquatic ecology is not generally a predictive science. Determination of cause and effect relationships where natural variables cannot be controlled, make data analyses of plant-induced impacts difficult. This is not to imply that monitoring for impacts should not be attempted. Rather, it means that surveys should be designed on the basis of what can be accomplished with current sampling methods and statistical analyses in differentiating aquatic changes caused by various factors. A possible shortcut to site-by-site impact prediction based on specific field and/or literature data, is the use of national chemical or temperature tolerance criteria. However, such national criteria generally tend to overestimate impacts at many sites in order to be completely safe at the most sensitive. If using these criteria requires costly designs, then would it be more appropriate to derive specific data for that site through field or laboratory bioassays. Another approach may be to collect and review the thermal impact data at operat-

Table 1.—Factors to be considered in design of thermal impact studies

(1) Recognize predictive limitations imposed by ecological state-of-art
(2) Obtain ecological information appropriate to stage of project development
(3) Limit ecological effort to those impacts relevant to specific site-plant combination
(4) Concentrate initial efforts on most sensitive organisms, with later expansion only if necessary
(5) Incorporate good biometric techniques in design of surveys
(6) Recognize value of uniformity in design, conduct and analyses of ecological studies in so far as appropriate

ing power plants having similar site-plant configurations and interrelationships. In short, survey programs should be developed from a practical standpoint of what can be accomplished in the field.

A second need is to recognize the specific objectives with respect to schedules for planning, construction, and operating steam electric power plants. This includes examining aquatic ecological information appropriate to the stage of project development. Information supplied out of sequence is often unnecessary. Also, the considerations used in the environmental assessment should be integrated with design engineering to weigh design cost against potential environmental costs.

A third need is to develop aquatic ecological information based on impacts that are critical for a specific plant and site combination. General survey information is often useful. It appears, however, that time, effort, and money have been wasted by surveys that were too broad and general. A rational assessment of effects of power plants on aquatic ecological systems requires well-planned ecological surveys which can detect impacts. Massive data collections which fail in this objective or achieve the objective with excessive redundancy, represent wasted effort. Compliance with regulations, and a utility's own economic interest, are both served by critical survey designs which address specific problems related to specific plant and site situations.

A fourth need concerns the sequence and priority of surveys for potential aquatic impacts. Some regulatory agencies request aquatic ecological information for essentially all trophic levels. This seems to stem from the fact that all trophic levels are interrelated so an impact at one level may be felt throughout an ecological system. However, from a practical standpoint, impacts initiated at one level take time to be reflected in others and are not generally reflected to the same degree. Thus it is more efficient to concentrate surveys on biota which are most sensitive to plant construction and operation and can be expected to be the first to be affected. These first-order groups are more often called indicator organisms. An early focus on these would allow surveys to be expanded to other trophic levels only if unacceptable impacts on indicator organisms were detected.

A fifth need is to incorporate good biometric techniques in survey design so that, significant plant-induced impacts can be distinguished from natural stresses. The experimental approach to assessment of impacts in the field is often not possible because of lack of controls. The evaluation of data obtained from sampling can only yield estimates of population size and survival rates. Impact evaluation must rely largely on approximate evaluation methods based largely on observational studies. Such an approach is presented in a recent report by Eberhardt and Gilbert (1974).

A sixth need is for greater uniformity in design, conduct, and analysis of aquatic ecological surveys. The advantage in working toward uniformity is twofold. First, it will result in making the license review process more efficient, and secondly, it will allow comparison of data from one site to another. This comparison could result in the development of a body of information for examining the ecological trends in a region and for making better estimates of the possibility of power plant induced impacts. This could also lead to more efficient design of environmental surveys for future power stations, and better design of the power stations themselves. Complete uniformity of surveys is not desirable because of the uniqueness of each site-plant situation. However, special or unusual surveys that are proposed on the basis of uniqueness should be carefully evaluated to avoid unnecessary surveys based on arbitrary personal preference of investigators.

A series of matrices (for examples see Figures 1–3 and Table 2) has been proposed corresponding to a checklist of possible data needs, or questions to be asked of the environment. These are to determine relative significance of parameters which have a credible connection to the proposed construction and operations of a power plant. Each matrix represents a survey stage and specifies parameters to be considered, indicates the temporal distribution of the data collections, and the quality of data to be gathered. It should be noted that the survey matrices were developed as a tool to determine information needs, not necessarily study requirements, since the desired information may be available from alternate sources.

The sequential information-need phases can be functionally subdivided into as many of the following stages as are useful in the specific case under consideration (Figure 4). The Site Selection Phase can be divided into an Initial Evaluation Survey to select candidate sites from candidate regions and a Site Selection Survey to rank those candidate sites. The Preconstruction Phase can be divided into an Initial Plant Design Evaluation Survey to obtain data needed for preliminary engineering, a Baseline Survey to obtain data needed for the environmental report and impact prediction, and where site exploration may be expected to cause significant environmental impacts, a Site Exploration Monitoring Survey. The Preoperational Phase can be divided into Construction Monitoring Survey to monitor construction activities and, if warranted, to sample

Survey Stage	Currents & Other Water Circulation Patterns	Flushing Rate	Existing Temperature Patterns	Bathymetric Conditions & Contours	Bottom Sediments & Sediment Transport	Salinity	D.O. of Water and Sediments	Turbidity	Dissolved Solids	pH	Nutrients	Manmade Chemical Stresses
Initial Eval.	1,A,I	1,A,I	1,A,I	1,A,I	1,A,I							
Site Select.	2,A,II	2,A,II	2,A,II	2,A,II	2,A,II	++	++	++	++	++	++	++
Baseline	4,E,III	3,B,III	4,E,III	4,A,III	4,A,III	4,E,II	4,C,III	4,C,III	4,C,III	4,C,III	4,C,III	4,C,III
Site-Plant Design Eval.	4,E,III	3,A,III	4,E,III	4,A,III	4,A,III	4,E,II						
Site Explor Monitoring					4,A,III	4,E,II	4,A,IV	4,E,III	4,A,IV	4,A,IV	4,A,IV	4,A,IV
Construc. Monitoring				4,A,III	4,A,III	4,E,II	4,B,IV	4,E,IV	4,B,IV	4,B,IV	4,B,IV	
Preoperation Survey	4,B,II	3,B,II	4,E,III	4,A,III	4,A,III	4,B,II	4,C,IV	4,C,IV	4,C,IV	4,C,IV	4,C,IV	4,C,III
Startup Monitoring	4,E,III	4,E,III	4,E,III		4,A,III	4,E,II	4,A,IV	4,E,IV	4,A,IV	4,A,IV	4,A,IV	4,E,III
Operation Monitoring	4,B,III	3,B,III	4,B,III	4,A,III	4,A,III	4,B,III	4,B,IV	4,B,IV	4,B,IV	4,B,IV	4,B,IV	

Figure 1.—Physical-chemical matrix.

for significant ecological changes; a Preoperation Survey to collect data necessary to provide baseline information for operational monitoring; and Start-up Monitoring Survey to include any special studies needed to identify significant changes in the ecosystem caused by various activities occurring during start-up. The duration of the Operation Phase is determined by imposed environmental technical specifications, but greater detail would normally be obtained for the initial operating years of the plant as opposed to later years of operation, in order to determine operating effects of the plant and to compare them with those predicted in the environmental impact statement.

All these aquatic ecological surveys should be considered, but implemented only if appropriate and necessary. If implemented, they should be designed

Survey Stage	Periphyton	Phytoplankton	Zooplankton	Macroinvertebrates	Macrophytes	Fish	Any Organism Category If Used
Initial Evaluation	1	1	1	1	1	1	
Site Selection	2	2	2	2	2	2	
Baseline	3	3	3	3	3	3	
Site-Plant Design Evaluation	2	2	2	2	2	2	
Site Exploration Monitoring							3
Construction Monitoring							3
Preoperation Survey	3	3	3	3	3	3	
Startup Monitoring							3
Operation Monitoring							3

Figure 2.—Highest quality level of information collected.

Table 2.—Key to level of biotic survey information

QUALITY OF INFORMATION

1. qualitative from available existing sources
2. qualitative from field observations
3. quantitative from field studies with statistical precision adequate for impact evaluation

FREQUENCY OF INFORMATION COLLECTED*

A. at least once by end of survey or annually if appropriate
B. quarterly
C. monthly
D. weekly
E. continuously
F. periodically**

GEOGRAPHICAL AREA STUDIED

I. regional
II. general site area
III. site impact area (for particular parameter)
IV. site impact area (particular parameter) plus control area

* While the key gives some guidance to the frequency of sampling, it does not provide guidance on best geographic spacing of sampling points. This is considered to be a site specific parameter best decided on a case by case basis.

** Periodically means sampling as often as a professional in charge of a survey considers necessary to identify a biotic change during the time it is likely to undergo the change.

Organism Groups	Ocean						Estuary						Lake						River					
	IS	PA	A	PR	S	SS	IS	PA	A	PR	S	SS	IS	PA	A	PR	S	SS	IS	PA	A	PR	S	SS
Periphyton																								
Phytoplankton																								
Zooplankton																								
Macroinvertebrates																								
Macrophytes																								
Fishes																								
Physical-Chemical	Refer to appropriate stage of Physical-Chemical Matrix 4.6																							

Figure 3.—Sample ecological matrix.

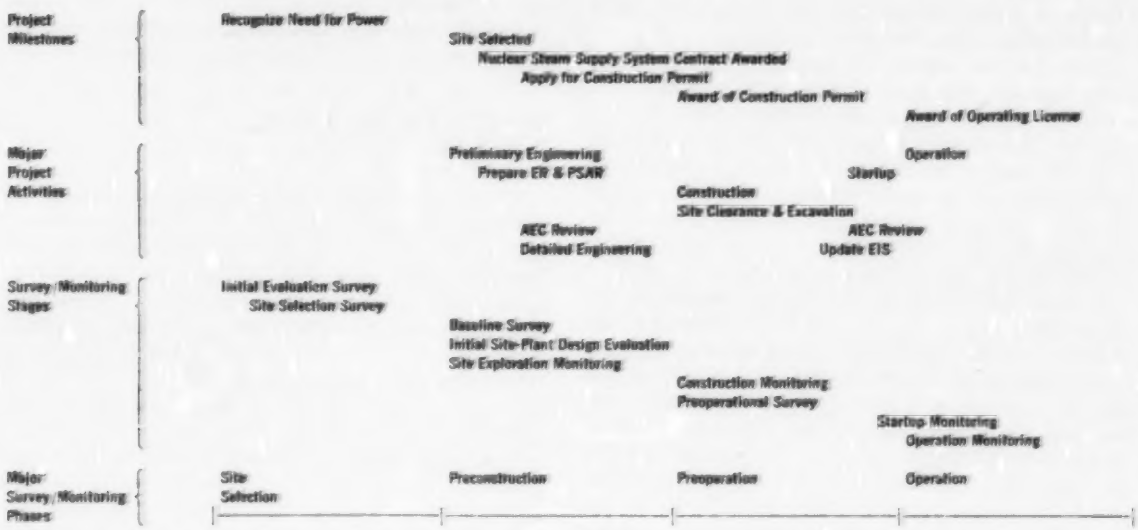

Figure 4.—Typical development schedule for nuclear power plants in the United States in 1974 with major survey phases and their corresponding survey stages indicated.

to evaluate potential impacts of plant operations on the biota of the immediate site area and to determine other information required by regulation. The potential major aquatic impacts to be considered are:

1. Attraction and impingement/entrapment of organisms by intake structures;
2. Entrainment of aquatic biota through the cooling system and resultant exposure to changes in thermal, chemical, physical and mechanical parameters;
3. Alteration of water quality in intake and discharge areas;
4. Scouring and silting of bottom habitat near intake and discharge structures;
5. Changes in water level or quality due to consumptive use;
6. Changes in currents in intake and discharge areas;
7. Thermal exposure of aquatic biota within mixing zone;
8. Blockage or delay of fish and shellfish movement by thermal or physical barriers;
9. Removal of habitats by structures.

The potential for these impacts will vary in importance between once-through and closed cycle cooling systems; therefore, plant design alternatives for the biological matrices acknowledge these variations.

Similarly, the ecological role or relative importance of each grouping varies from site to site. Some sites for example may have few or no important fish, or macrophytes, or may have poor substrate for supporting benthic invertebrates. Groupings actually selected for study at each site should be based on professional biological judgement. The life stage of a particular group to be studied should depend on specific site circumstances and the potential impacts to be evaluated. Thus the matrices present the highest level of information suggested for each organism grouping in relation to various survey stages. The purpose of the matrix is to serve only as a check list to be certain such groups are considered for possible inclusion in studies, and it may frequently happen that study will show that some groups should be included, and that others have no credible link to a specific proposed power plant project.

Consideration ought to be given to those organism groupings and important species within each which would be utilized to evaluate the aquatic community at a site. Important species or groups are those most valuable and/or vulnerable by the criteria set by civilization, but presumably will include protection of major food-web pathways. Certainly it would be unnecessary (and impossible) to study all or most species within each organism grouping at a site.

Species considered should be of commercial or recreational value, threatened with extinction, or dominant at the specific site. If a species is essential to the maintenance of an important species it should also be considered. Important species should have some plausible relationship to power plant operation. Abundance or biomass of the species should be such that sampling can occur without serious depletion of the organism population. Species selected would hopefully have taxonomic characteristics which would facilitate accurate identification.

For those important species or organisms, detailed studies may need to be conducted so plant-induced impacts can be estimated and separated from natural variations. In the early survey stages preliminary estimates should be made of the particular role of each organism grouping, at the site under consideration, in order to determine whether important species are within the group. Following selection of a site, greater consideration should be given to determining important species and important organism groupings. A checklist of organisms likely to be especially vulnerable to the specific stresses proposed should be developed.

Throughout all surveys, the site-plant design evaluation should be performed through evaluation of site specific information. The purpose of this evaluation is to note ecological information on sensitive or critical biological aspects of the site that need to be designed around. The following are examples of structures, systems, and plant outputs which could affect aquatic ecological conditions and for which alternatives exist for modifying the potential impacts: maximum thermal power output, locations of major structures, type of cooling water system, location of access roads, rail lines, and transmission line rights-of-way, locations and designs of intake and discharge structures, and types of radiological, chemical, and biocide waste discharge systems. Initial information must be available from the ecological studies at the early baseline survey stage so that such data can be used in a timely evaluation during preliminary engineering of the plant. The aquatic ecologist in charge of the baseline survey should consider, even on the basis of just a few months of data from the initial survey, what aquatic aspects of the site are important to safeguard.

OPTIMIZING SEARCHES FOR EXISTING DATA

Finally, one must address efficient solutions to the problems presently inherent in obtaining necessary biological information for environmental reports from literature. Currently, it is not really possible to keep up with the tremendous quantity of data, and interpretation, appearing each year in the published technical literature, and very difficult to even learn what data have been collected but not published at all, or published only in the "grey" literature of informal or internal reports.

One may first try to use available biological literature research tools, such as BioAbstracts, Oceanic Index, et cetera, and within limits they are rather easy to use, if one wants to locate information either in very broad categories such as physiology, or taxonomy, or in very narrow categories such as one specific organism. While these indexing categories are quite helpful to research projects concerned with a single species, and perhaps a single aspect thereof, they are of extremely limited use to those who need to quickly and efficiently locate existing knowledge relating to a specific geographic location. This then is a basic need of bio-environmentally oriented scientists and engineers working with both industry and regulatory agencies.

It appears, however, that several potential solutions are almost available; that is "almost available" in the sense that they have been applied successfully to similar purposes.

At least two computerized systems are now in use for storage and recovery of physical-chemical water quality data: The Environmental Protection Agency

(EPA) STORET system and the National Oceanographic Data Center (NODC) files. In each of these a search can be conducted on the basis of geographical location (and by chronology). The NODC data can be retrieved by Marsden Squares—each of which includes a large number of square miles, but a size which is not inappropriate to the relatively gentle gradients characterizing oceanic parameters. The EPA STORET system is accessible by specification of either geographic points (river-mile, or latitude/longitude) or area (between river miles indicated as up and downstream boundaries, or within a polygon each apex of which is indicated by latitude and longitude). The further ability to sort the data chronologically to contrast recent vs. older data, or to look for seasonal patterns, is a significant additional aid to ecological analysis.

Another major source of information, which also needs improved indexing, is the vast compilation of data in the variety of water-use permit applications: NPDES, Section 316, and federal, state and local environmental impact statements. A comprehensive index to these on a geographic locator system would be extremely valuable.

Other major literature search services, e.g., BioAbstracts, Oceanic Index, and the Smithsonian Institution's Science Information Exchange, are set up for "keyword" access searches.

Only a negligible, relatively minor expense would be involved to ensure that a geographic locator, a keyword, or latitude-longitude specification, were used also in all papers/reports that relate to field biological studies, or even those studies which utilize organisms collected at field-locations. One must assume of course that authors would cooperate, and provide the needed information in the paper/report (and in its abstract submitted for use of literature search tools). Once that habit was ingrained, the addition of this one extra index would represent a very low cost to index services in absolute terms, let alone in relation to the benefits accrued in being certain all relevant data are integrated into impact statements. If such geographic locators were to include latitude-longitude, in addition to a named body of water (lake, ocean, watershed, river basin), or land area, utilization would be greatly enhanced by the easier incorporation of references into the STORET/NODC type systems with a numerical index access, without need for knowledge of the name of each body of water or land area.

Similar organization of air quality data by "airshed" would greatly enhance full use of existing knowledge in overall evaluation of more complete environmental interactions.

Thus the key to continued progress in making knowledgeable, realistic, and consistent evaluations on environmental impact lies with improving both the comprehensiveness of the data base available—at reasonable cost—and improving our ability to determine which data are indeed important to the decision under consideration.

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THERMAL DISCHARGES AND ESTUARINE SYSTEMS

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ABSTRACT

Interactions between steam electric station operations and estuarine aquatic systems are described. Environmental problem areas are discussed under two broad categories: (1) the predator role of a power plant in terms of larger organisms impinging upon water intake structures, or of effects on smaller organisms upon passage through cooling water condenser systems; and (2) the discharge water or plume impact on resident and migratory organisms in the receiving water. Biological damaging effects are described from many factors other than excess heat alone, e.g., mechanical, biocides, et cetera. A number of siting and operating design options to achieve better compatibility are described. Integration of field and laboratory programs is urged at both national and regional levels. Present trends are reviewed. Four recommendations are made with regard to national and regional policies. Seven recommendations are made with regard to research activities.

INTRODUCTION

Management, research and legislative concern with the environmental problem of excess heat production from the electric generating industry have spawned the development of many new terms in the last 10 years. Thermal pollution, thermal loading, thermal addition, thermal enrichment, and calefaction are the more common ones now used. This same period, especially the last five years, has seen the production of numerous bibliographies, national and international symposia and workshop volumes, review treatises, journal publications on basic and applied research results, legislative committee documents, "pre- and post-operative" survey reports, consultant reports, and environmental impact statements, all in some manner pertinent to the problem caused by excess heat release due to an activity of man.

In spite of the above described efforts, a consensus of opinion as to whether thermal discharges have significant environmental effects on a site or region is difficult to obtain. This difficulty can be traced to a number of factors, among them:

1. Inadequacy of research data, attributed to:
   a. The inability of field studies to overcome the "noise" in natural systems caused by inherent natural variations.
   b. A lack of coordinated and well-designed investigations (both field and laboratory) of a regional or national scope. We are still shot-gunning and not always asking the right questions.
   c. A relatively large segment of the research community being reluctant to engage in applied research.
2. Adherence to traditional economic-ecologic philosophies or activities.
   a. As stated by recent administrations in Washington, energy independence and economic recovery are believed best achieved by relaxing environmental concerns.
   b. External diseconomies are still permitted with regard to environmental losses, sometimes because of an inability to factor environmental values into economic input-output models.

Thus, the man-environment excess heat problem has not been solved, or resolved, and with regard to waterways, the volume of thermal discharges has been increasing.

WHAT IS THE PROBLEM?

Although all excess heat must eventually enter the atmosphere, traditionally water has been used as a "middle man" to carry excess heat energy away from steam electric stations (SES). Water's unique characteristics have provided useful economic and engineering advantages to the electric utility industry. These advantages have in turn been reported as disadvantageous to aquatic resources (see Clark and Brownell (1973) for one such treatment).

In general, for every 1 megawatt of electricity produced, 1.7 megawatts of heat are rejected by a

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steam electric station, corresponding roughly to 33 percent energy conversion efficiency for a typical fossil fuel plant (Engstrom, Bailey, Schrothe, and Peterson, 1972a). New fossil fuel units achieve about 40 percent efficiency while nuclear units achieve about 32 percent efficiency. A typical water requirement for a 1000 MW_e[1] installation is about 1,500 cubic feet per second. Taking into account differences in plant and stack heat losses, fossil fuel units reject about 4.2×10^9 BTU/hr., while nuclear units reject about 6.6×10^9 BTU/hr. to the condenser cooling water supply. Thus, average increases across condenser systems are 12°F for fossil and 20°F for nuclear (Committee on Power Plant Siting, 1972). Increasing size of single installations may require up to 50 square mile feet of water per day to be pumped for condenser cooling purposes if open once-pass systems are used to dissipate excess heat. Environmental concern with regard to excess heat in aquatic systems stems from the acknowledged role of temperature as the biological master factor in these same systems (Kinne, 1963; Mihursky and Kennedy, 1967).

OPERATING CHARACTERISTICS OF OPEN ONCE-PASS COOLING SYSTEMS OF STEAM ELECTRIC SYSTEMS PERTINENT TO BIOLOGICAL EFFECTS

Given on Figure 1 is a schematic of an open once-pass cooling water system used in a typical steam electric station design. Included also are three columns: (1) Design Parameter, (2) General Preference and (3) Ecological Basis. Although thermal effects have gained the most attention as a possible limiting factor of SES on biological systems, the above figure calls attention to a number of additional features that may affect resident biota. Mechanical damage may occur to organisms such as fish, crabs, combjellies, jellyfish, and salps that impinge on intake screening. Smaller organisms, e.g., phytoplankton, zooplankton, fish eggs and larvae, that are pumped into and through the cooling water system can be mechanically damaged from impingement on the ends of condenser tubes and from moving parts of pumps. These same "pumped-entrained" organisms can be subjected to pressure changes, turbulence (shearing forces) as well as to damaging effects from biocides such as chlorine which are used to keep metal surfaces clean of fouling organisms (Coutant, 1970).

Still other more complex consequences of SES operations must be understood. One, for example, is the use of chlorine as a biocide. Although the chemistry of chlorine in seawater is imperfectly known, information indicates that not only can chlorine kill organisms but it can oxidize the organic component of bottom sediments and thus release absorbed heavy metals (Hill and Helz, 1973). These effects, especially when combined with heavy metal releases from SES condenser systems due to erosion or corrosion (Leschber, 1972) can result in magnifier-concentrator organisms such as shellfish incorporating and accumulating excessive levels of metals and consequently being rendered unfit for human consumption (Roosenburg, 1969). Becker and Thatcher (1973) have produced a review publication entitled "Toxicity of Power Plant Chemicals to Aquatic Life." This review discusses the various chemicals actually or potentially associated with power plants. Eighteen chemical categories and over 125 separate chemicals are listed.

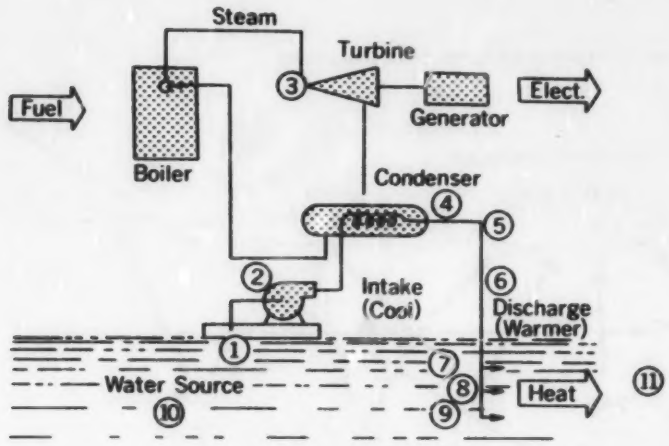
From an aquatic resource viewpoint, two major considerations are important when SES employ open, once-pass cooling systems (Figure 2). The first is the concept of the SES acting as a predator and "cropping" or consuming organisms, the so-called pumped-entrainment and/or pumped-entrapment effects. Thus, site selection, engineering designs and operating characteristics for minimum biological damage becomes critical under such circumstances and the relative rates of destruction and recovery must be determined. If plant operations "crop-off" organisms at a rate faster than organisms can regenerate in open receiving systems, depletions in natural populations can be expected (Mihursky, 1969).

The second consideration deals with discharge plume effects on near-field and far-field biota. Discharge plumes may have various physical configurations depending upon the characteristics of the receiving water body and the design and location of the discharge structure itself (Committee on Power Plant Siting, 1972). Biological effects of plumes are determined by the following factors:

1. Temperature elevation
2. Rates of temperature change
3. Chemical characteristics
4. Hydraulics

Abnormal migrations of mobile animal species into and away from discharge plumes (Elser, 1965; Moore, et al., 1972; Trembley, 1960) and occasional massive kills (Alabaster and Downing, 1966; Mihursky, 1969; Trembley, 1965; Wagenheim, 1972) under various seasonal and SES operating conditions are recognized facts. Positive as well as negative responses on the part of non-mobile benthic plant and animal species are also known to occur (e.g., Anderson, 1969; Cory and Nauman, 1969; Nauman and Cory, 1969; Warinner and Brehmer, 1966).

[1] 1000 MW: 1,000,000 kilowatts of electricity.



DESIGN PARAMETER	GENERAL PREFERENCE	ECOLOGICAL BASIS
1. Intake design	Behaviorally avoidable or provide safe return to environment	Poorly designed intakes trap fish, crabs, etc.
2. Volume of water pumped	Low (but site dependent)	Numbers of organisms affected
3. Turbine backpressure	Lowest feasible heat rates	Lowest backpressure permit low temperature discharges to environment (7) highest feasible efficiencies
*4. Temperature rise	Site and season dependent	Temperature-time relationships of effects
5. Length of cooling water piping in plant	Short (minimum transit time)	Temperature-time relationships of effects on entrained organisms
6. Length of transit to receiving waterway (canal or pipeline)	Short (minimum transit time)	Temperature-time relationships of effects, fish entrapment
7. Discharge location	Beyond littoral contact	Shoreline abundance of organisms (may be seasonal)
8. Discharge depth	Semistratified plume	Keep highest temperature water away from resident bottom organisms
9. Turbulence (exit velocity, port size or number)	High	Temperature-time relationships and areal extent of effects
10. Dilution (near field)	High	Plume entrainment, temperature-time relationship
11. Circulation (far field)	High	Temperature buildup for recirculation may change overall species composition

*Subject to mutual trade-offs at specific sites.

FIGURE 1.—Schematic of once-pass cooling water design and a summary of cooling system design needs (from Committee on Power Plant Siting, 1972).

SOME MAJOR UNANSWERED QUESTIONS

In brief, although the major interactions between SES and aquatic environments can be reduced to (1) pumped-entrainment and entrapment (= predation) and (2) discharge plume effects (= behavior, growth and reproduction), and many studies have attempted to sort out biological responses and identity limiting factors, no single study has really

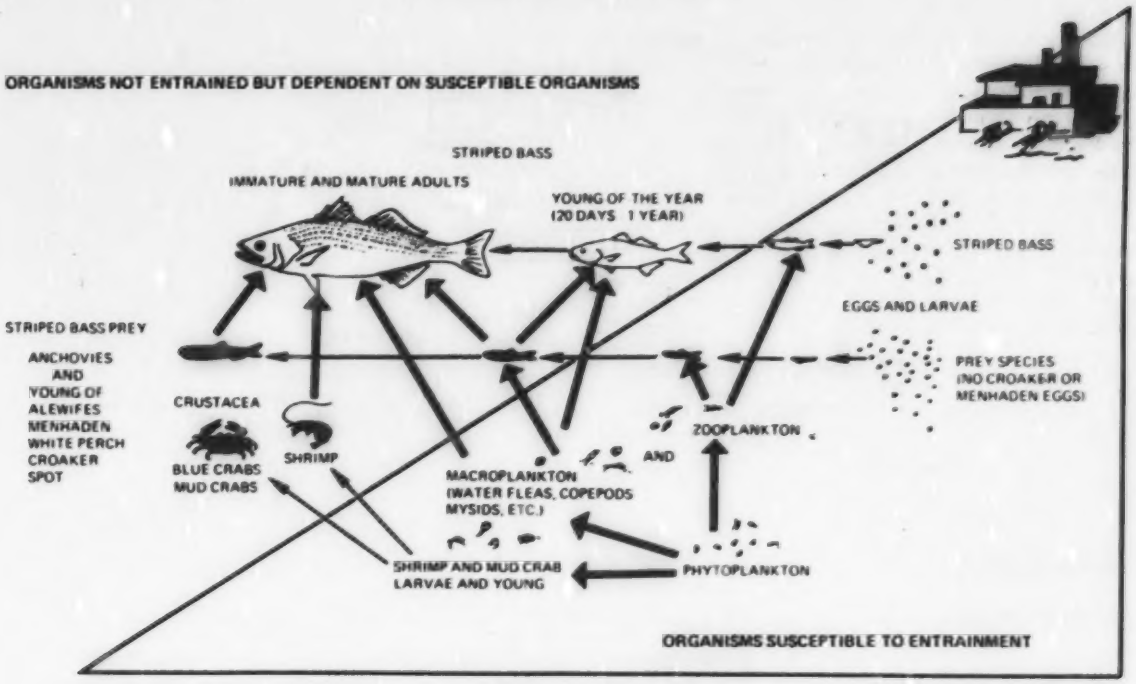


FIGURE 2.—Potential power plant effects on striped bass and associated food items (from Bongers et al., 1972).

answered the two most important questions:

1. Regardless of whether biological community structure has been altered (different species mix or different relative abundance of various species), is biological energy flow still going into the production of a similar quantity of useful biological material as occurred before any SES influence?
2. If concern is for one or more target species, are socially (= man's interest) acceptable sustained yields still produced within the estuarine system or subsystem for the species in question?

These questions are not easy to answer; however, let us briefly examine some of the information that should be acquired if we seriously try to answer them and thus manage the energy-environment question from a scientific as opposed to a political, economic or emotional point of view.

1. Develop a better understanding of the processes operative within estuaries.
   a. Understand the population dynamics of key estuarine organisms.
   b. Determine limiting factors to a species' success, e.g., predator-prey, host-disease, host-parasite relationships, food web relationships (who eats what and how much), physical and chemical threshold levels for biological success at the species and community level.
   c. Determine sources, cycles and sinks of critical (or limiting) items, e.g., heavy metals, biological energy and material flow.
2. Develop biogeographic maps of estuarine systems, identifying the following for key species:
   a. Quantitative seasonal and daily distributional patterns in both horizontal and vertical gradient systems for all life history stages.
   b. Spawning areas.
   c. Nursery areas.
   d. Over-wintering areas.

FIELD VERSUS LABORATORY RESEARCH

The importance of properly coordinated field and laboratory programs cannot be overemphasized. Development of typical information needed requires considerable laboratory as well as field efforts to understand the processes operative within estuarine systems; biogeographic mapping must depend on extensive field operations.

The variability inherent in field data due to patchiness in distribution of organisms both temporally and spatially, will require one of two approaches: (1) improve the design, sampling effort, and methodologies to increase field quantification; or (2) assist judgements through the use of appropriately designed laboratory experiments.

Approach #1 will add greatly to the cost of traditional field studies. As an example, our present program to understand the population dynamics of one species, the striped bass, and the relationship to power production in the Potomac Estuary, Md., required the following for 1974:

Sub-program	*Staff*	*Direct Costs*
Spawning stock assessment	8	$ 90,000
Ichthyoplankton	10	125,000
Hydrography	7	75,000
	24	$290,000

If indirect costs are added, the total dollar expense would approximate $500,000 for a coordinated field project that is attempting quantification for a single fish species. As another example, Carpenter's (1974) recent analysis of the number of zooplankton field samples needed to accurately quantify the community at a single station for a single collection date at the 5 percent confidence level was over 300 discrete samples! Carpenter's work also is being applied to power plant investigations. Such large field efforts are not always possible due to limited funds or staff.

Lack of statistically valid field quantification forces one to resort to judgements. Such judgements can be greatly improved if laboratory studies, coordinated with field programs, are permitted to assist in decision making. In many cases, laboratory programs can provide exceptional insight and information at modest cost. For example, recent laboratory work on time-temperature mortality experiments on egg and larval stages of some estuarine shellfish species (Kennedy, et al., 1974) required the direct capital outlay of less than $2,000/year. Indirect costs (inhouse salaries) were less than $30,000/year. This latter work singled out various temperatures and time exposure combinations necessary for survival (Figures 3, 4, and 5). Such data cannot be acquired under field conditions; however, they are useful and necessary to be incorporated into population dynamics studies, pumped-entrainment effects and development of engineering designs and operating characteristics of SES.

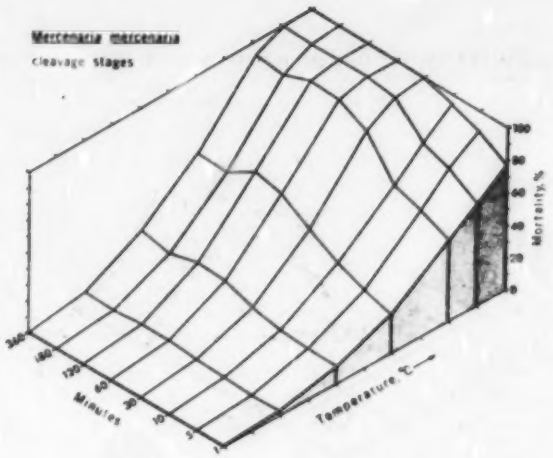


FIGURE 3.—*Mercenaria mercenaria* cleavage stages. Response surface generated from multiple regression analysis of percentage mortality on temperature and time (from Kennedy et al., 1974).

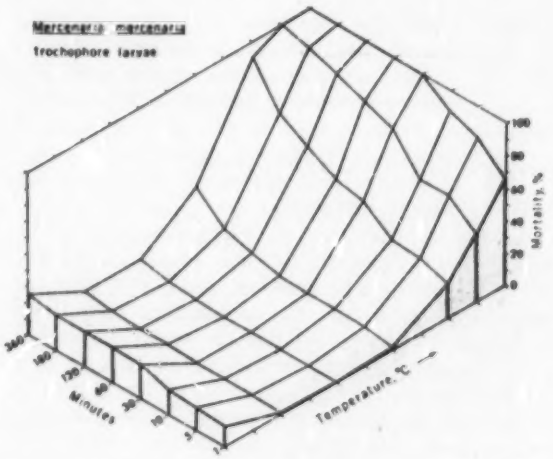


FIGURE 4.—*Mercenaria mercenaria* trochophore larvae. Response surface as in Fig. 3 (from Kennedy et al., 1974).

SOME EXAMPLES OF SITING AND ENGINEERING DESIGN OPTIONS

From an aquatic resource viewpoint, SES sites should be selected on the basis of two considerations: (1) Avoid sites that are environmentally vulnerable to SES activity; (2) Locate in estuarine areas that have environmental and biological flexibility to accept SES operations. In order to achieve the above one must first have adequate knowledge of the biogeography of the region and understand the

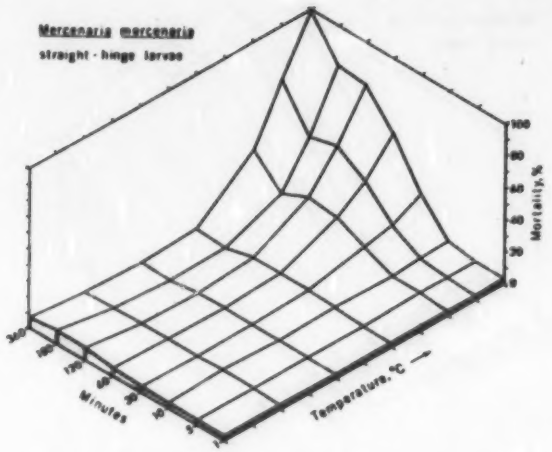


FIGURE 5.—*Mercenaria mercenaria* straight-hinge larvae. Response surface as in Fig. 3 (from Kennedy et al., 1974).

processes responsible for maintaining its biological integrity and utility. For example, within the Chesapeake system the striped bass is an extremely important commercial and recreational species providing social and economic value to the region. The species' spawning sites have been identified (Fig. 6) and are recognized as important geographic areas that seasonally contain concentrations of critical life history stages of this species.

A number of such critical estuarine zones can be identified and located. Similarly, within the Chesapeake system, oyster growing areas, and areas of important "seed" or spat production have been described. Protection of this extremely important economic species dictates that areas of high seed production not be encroached upon by industrial operations requiring large volumes of water for process purposes. The oyster management program in the bay system depends on redistribution of the spat from these areas of high production, but slow growth, to other areas of low or no production, but high growth.

Certain environmental flexibilities can be recognized within estuarine systems if one appreciates their basic characteristics. For example, greater volumes of water (mass flow) move by a point in an estuary as one proceeds from the low salinity inland reaches to the higher salinity, oceanic end. Thus more water is available for dilution purposes. Biologically speaking, along this same salinity gradient (from low to high salinities) the biological value of a given cubic meter of water seems to decrease, e.g., primary production rates decrease, quantities of fish eggs and larvae decrease (Dovel, 1970). Thus, if a given volume of water must be utilized or sacrificed, lesser biological damage per unit volume of water would occur as one progresses from the lowest to the highest (oceanic end) salinity reaches.

Concurrently, SES engineering design and operational characteristics must factor in other biological information to avoid damaging effects on existing biota:

1. Multiple intake and outfall options must be considered for any given site. A surface water intake may be desirable in the daytime when plankton are concentrated in bottom waters, while a bottom night-time intake location may be desirable when plankton organisms tend to migrate to surface waters (Figure 7). Such strategies are capable of minimizing pumped-entrainment of planktonic organisms. Similarly, an offshore deepwater intake may be optimum in summer while a nearshore shallow intake may be optimum in winter due to temperature and water quality advantages as well as differences in distributional patterns of organisms.

2. Volume of cooling water pumped can be manipulated in order to increase or decrease temperature elevations or the number of pumped-entrained organisms. This approach may have value if mechanical or shearing forces are limiting, rather than temperature. Under these circumstances, minimizing water volume pumped can minimize cropping below limiting levels for planktonic organisms. On the other hand, if an absolute temperature is limiting to a site, and "spreading it thin" is possible without other limiting factors operative, then simply increase pumping volumes.

3. Similarly, if biocide use for cleaning purposes is limiting (Becker and Thatcher, 1973), dilution may be one solution; however, use of mechanical cleaning devices such as recycled sponge or brush balls in condenser systems are decidedly to the advantage of the biota.

4. Manipulation of discharge plume characteristics (Committee on Power Plant Siting, 1972) has decided biological advantages. Where important, one may wish to (a) keep the plume in surface waters in order to avoid impingement on important benthic species, (b) minimize surface to bottom gradients so as not to interfere with diurnal vertical migration patterns (Gehrs, 1974), (c) maximize high grade heat zone, or (d) maximize low grade heat zones.

5. Alternation of cooling systems to accommodate the biota also has utility. Critical and entrainable early life history stages may be present at a site only for one or two months (Figure 8); at such time an SES could switch from an open once-pass cooling

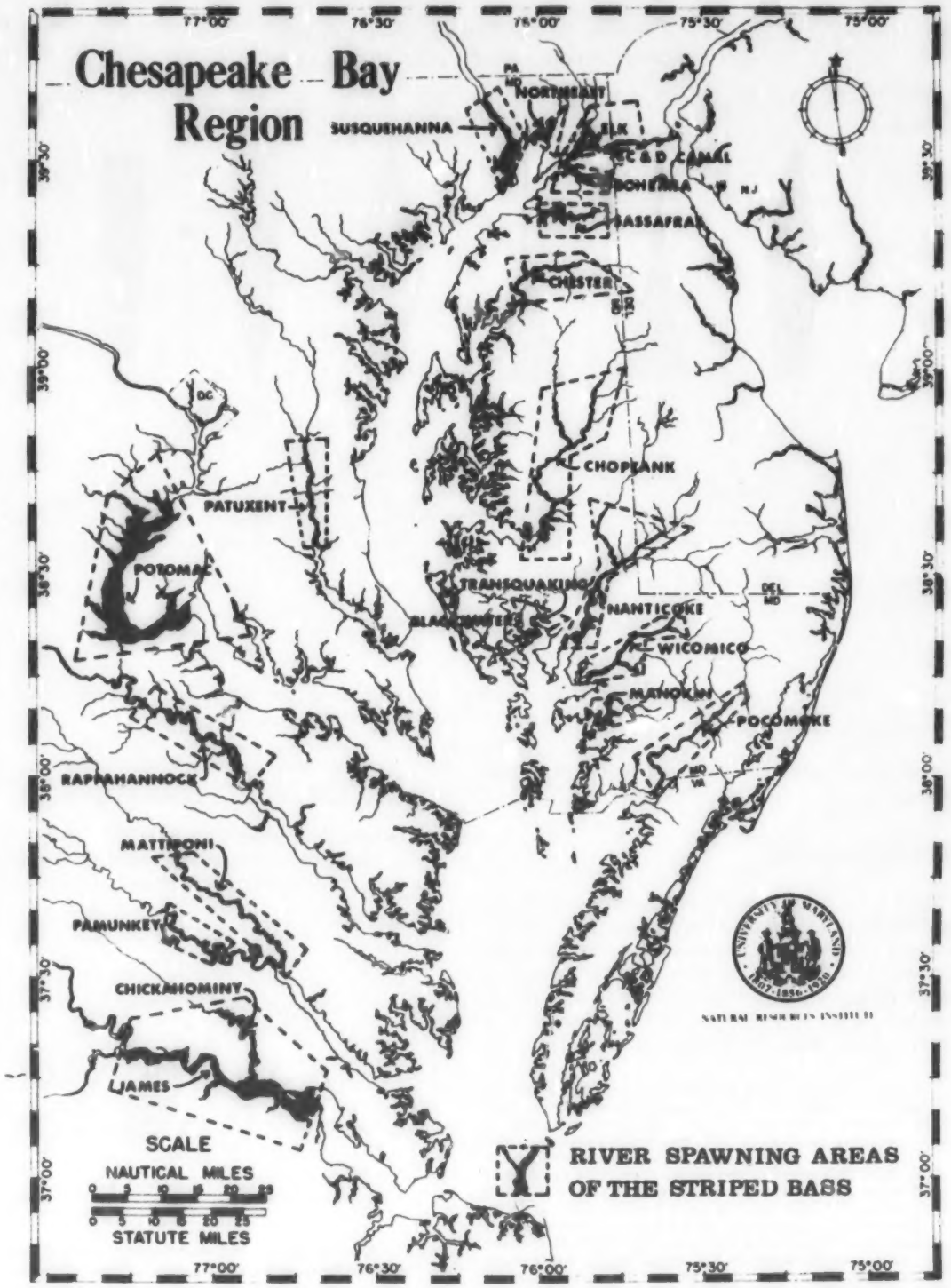


FIGURE 6.—Distribution of striped bass spawning areas in the Chesapeake Bay region.

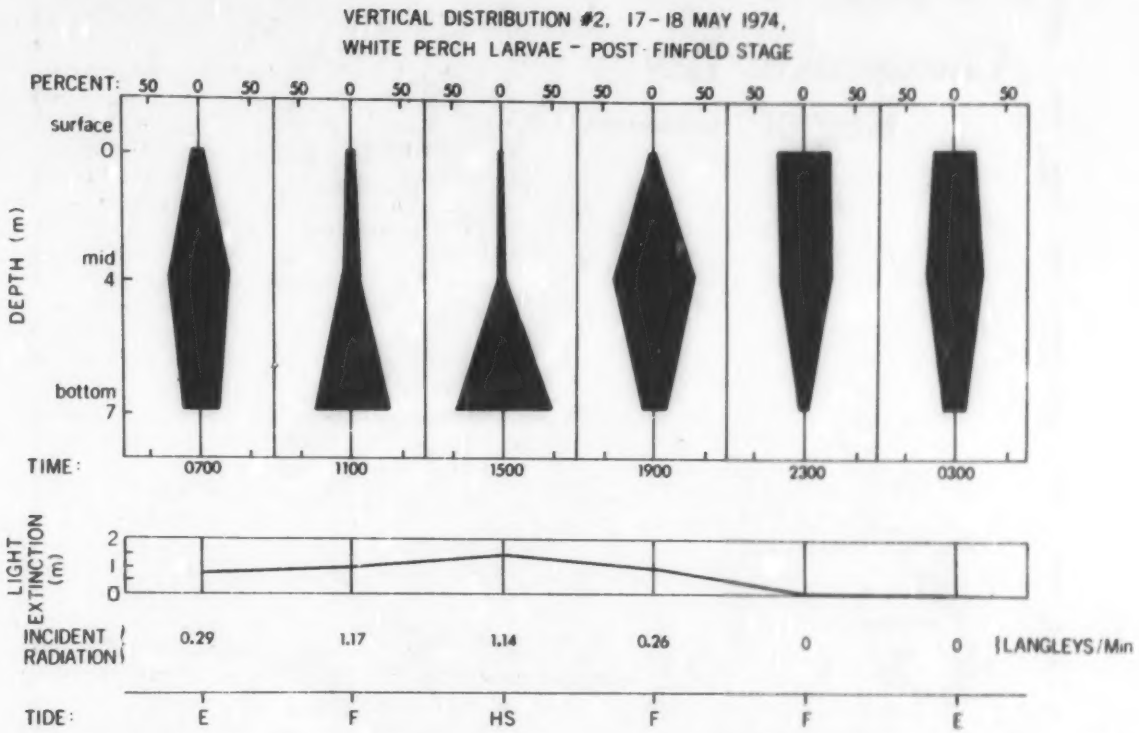

VERTICAL DISTRIBUTION #2, 17-18 MAY 1974,
WHITE PERCH LARVAE - POST FINFOLD STAGE
PERCENT: 50 0 50 50 0 50 50 0 50 50 0 50 50 0 50 50 0 50
surface
0
mid
4
bottom
7
DEPTH (m)
TIME: 0700 1100 1500 1900 2300 0300
LIGHT EXTINCTION (m)
2
1
0
INCIDENT RADIATION 0.29 1.17 1.14 0.26 0 0 LANGLEYS/Min
TIDE: E F HS F F E

FIGURE 7.—Kite diagrams giving percent vertical distribution of white perch larvae (post-finfold stage) at a single station in the Potomac Estuary over a 24-hour period.

system to a closed or semi-closed one to minimize damage.

PRESENT TRENDS

Many projections have been made on regional, national and world-wide energy needs. The increase in our national energy demand curve has been impressive. Exactly what our growth will be in view of recent energy supply developments is difficult to ascertain. The recent discussion by Mihursky and Cronin (1973) gives one prediction:

> Based on 1960 estimates of U.S. population of 300 million by 2000 A.D., energy usage per capita is expected to increase some 250 percent, and electrical energy is expected to increase by 1,350 percent in the same period (Figures 9 and 10). Electrical energy use is projected to go from 24 percent of the national energy consumption total in 1970 to 34 percent in 1980, 42 percent by 1990 (Anon, 1970) and to 52 percent by 2000 (Jaske, 1970). However, . . . Lees (1971) stated that . . . even assuming near zero population growth, a drop to one half of the present rate of growth in individual wealth, and a corresponding 50 percent reduction in the current rate of increase in power use in the next decade, U.S. consumption of electricity will still triple by 1990! (See also Hammon, Metz and Maugh, 1973). Landsberg (1970) indicated that increases in per capita consumption has accounted for 90 percent of electric generation since 1940.

It seems that in spite of possible changes in life styles, and consequent energy use and consumption patterns, substantial growth demands for electricity

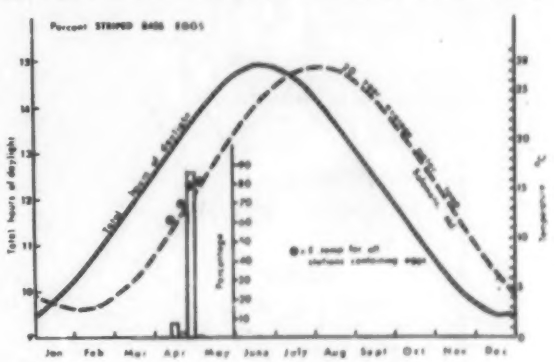


FIGURE 8.—Percent weekly abundance of striped bass eggs in Potomac Estuary for 1974 plotted against total hours of sunlight and 20 year average surface water temperature at Solomons, Md.

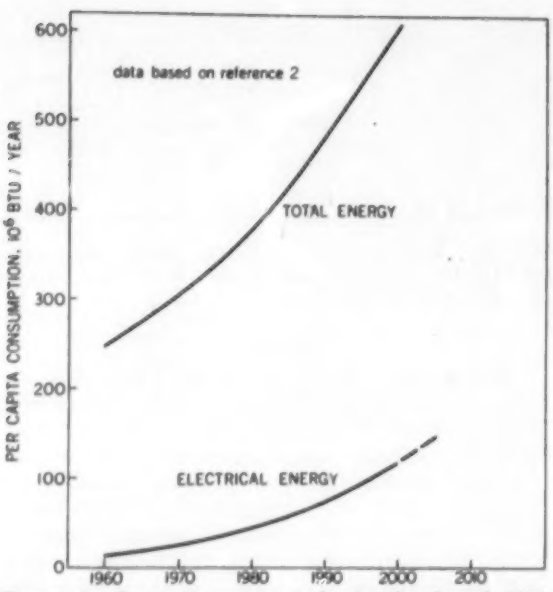


FIGURE 9.—Per capita energy use by decades through 2000 A.D. (from Jaske, 1970).

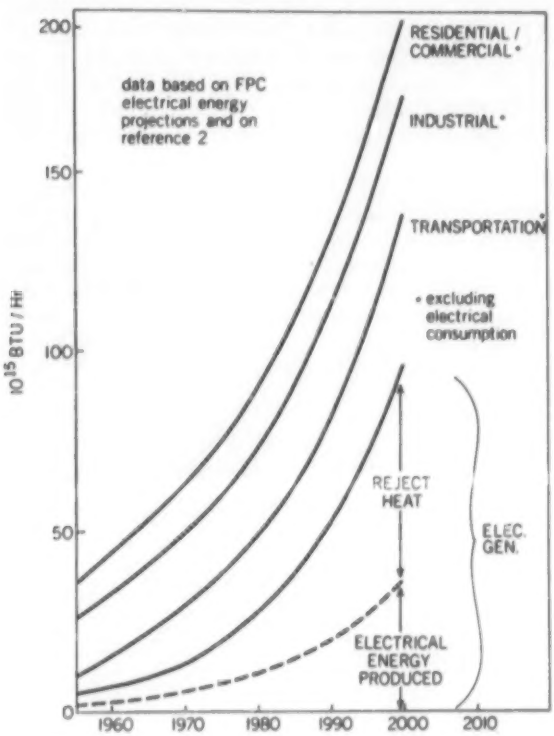


FIGURE 10.—Projected total energy demand in U.S. (from Jaske, 1970).

will continue. Present methods of electricity production still require large volumes of water for excess heat dissipation. Examination of alternative electricity production schemes for the near term (to year 2000) and long term (after year 2000) is possible. Table 1 lists information on electrical power generating technologies and presents data and estimates for three categories: (1) present systems such as hydroelectric, fossil and nuclear fueled SES, and gas turbines; (2) developing systems for the short term (1970–2000) such as breeders, magneto-hydrodynamics, and geothermal; and (3) developing systems for the long term (after year 2000) such as thermoelectricity, fusion, and solar. In summary, the major energy conversion systems presently employed and available for the near term (to year 2000) dictate that great quantities of waste heat will be discharged into our environment.

The next question is where and how the waste heat should be discharged. Recent studies evaluating waste heat assimilation capacities of various river basins of the U.S. as determined by limitations imposed by present state water quality standards, conclude that much of these existing water resources are insufficient to cool on a once through basis, the anticipated growth in the electrical generating industry (Engstrom, et al., 1972a, b).

It seems, therefore, that SES siting efforts by industry will continue towards larger water bodies such as the Great Lakes, estuaries, coastal and nearshore coastal zones. Recent rulings by the Environmental Protection Agency (1974) with regard to the possible use of cooling systems other than once-pass, e.g., cooling towers, has recently added

Table 1.—Estimated reduction in striped bass young of the year*

	Percentage Reduction According to Flow Year Simulated						
	1949	1955	1964	1967	1968	1969	1970
CONDITION							
No plants (base)	0	0	0	0	0	0	0
Danskammer	5.9	4.5	10.5	6.7	1.8	3.4	4.8
Lovett	12.4	16.0	9.5	9.7	4.5	15.6	15.1
Bowline	13.9	18.4	10.6	9.7	21.9	22.6	18.5
Roseton, Danskammer	15.1	12.2	23.7	16.9	5.3	9.4	12.8
IP 1 & 2	32.9	42.8	25.6	26.8	14.4	41.7	39.9
Roseton, Danskammer, Lovett, Bowline	37.1	40.9	40.4	33.3	29.2	41.5	40.5
Roseton, Danskammer, IP 1 & 2, Lovett, Bowline	55.4	64.0	54.4	48.7	38.2	63.8	61.4

* Assuming flow conditions similar to the year specified.

another dimension to the economic and engineering aspects of SES construction and siting by the industry. As presently stated:

> With respect to any point source otherwise subject to the provisions of section 301 or section 306 of this Act, whenever the owner or operator of any such source, after the opportunity for a public hearing, can demonstrate to the satisfaction of the Administrator (or, if appropriate, the State) that any effluent limitation proposed for the control of the thermal component of any discharge from such source will require effluent limitations more stringent than necessary to assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is to be made, the Administrator (or, if appropriate, the State) may impose an effluent limitation under such sections for such plant, with respect to the thermal component of such discharge (taking into account the interaction of such thermal component with other pollutants), that will assure the protection and propagation of a balanced indigenous population of shellfish, fish and widlife in and on that body of water.

The final operating procedure may or may not require a greater use of alternate cooling systems such as cooling towers than as had been required in the past. Many alternate wet-evaporative cooling methods require considerably less water than open once-pass systems (≈2 percent); however, chemical discharges are increased from blow-down cleaning of cooling towers (Becker and Thatcher, 1973). Hence, in estuarine systems the investigator may have a new task to contend with, namely, cycles, sinks and biological responses to a large array of chemical compounds.

The interaction between the electric utility industry and biologists is expected to continue. Increasingly, industry will continue to develop less damaging operations in response to biological and environmental data.

Examples of such improvements are given in Figures 11 and 12, which are schematic illustrations of water intake and discharge arrangements of two SES on tidal arms of the Chesapeake Bay in Maryland. These illustrations indicate temperature elevation patterns and transport times of cooling water from point of intake to point of discharge into the estuary. Scheme one (Figure 11) reflects an old design (built in the early 1960's) that has summer temperature elevations across the condensers of 6.5°C and a transport time from intake to discharge in the estuary of 2.7 hours. Discharge temperatures reached nearly 38°F, within the old water quality standards of the state. The recessed cooling water intake is located in a relatively shallow shelf zone. This installation used chlorine to keep heat exchange surfaces clean of fouling organisms.

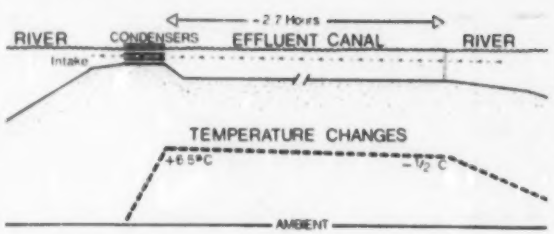


FIGURE 11.—Cooling water system design, temperature changes and discharge time for the Chalk Point SES on the Patuxent Estuary.

Scheme two (Figure 12) is the design of a new plant by the same company. Intake water is from cooler and deeper zones (30–50 ft.) and water transport time is 15 minutes from intake to the estuary. Ambient temperature estuarine water is added immediately on the discharge side of the condenser in order to augment temperature reduction. Maximum temperature differential between intake and outfall water is designed to be 5.2°C and the summer discharge maximum is designed to be approximately 32.2°C, which is about equal to the maximum reached by surface waters in the bay under natural conditions. The above conditions meet the new state water temperature standards. In addition, condenser cleaning is assisted by using sponge rubber balls forced through the cooling system. Scheme two has less effects on entrained organisms than scheme one.

The existing temperature isotherms for a cross section of the Chesapeake Bay for a typical summer day are given in Figure 13. Notice that the hottest temperatures occur at the surface and on the shelf zone. SES have typically pumped cooling water from this shallow shelf zone, the zone that naturally is the hottest during the summer. In the Chesapeake Bay a number of important animal species are at

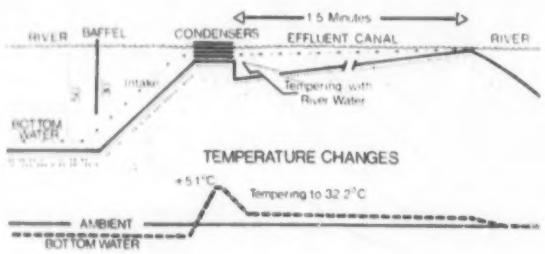


FIGURE 12.—Cooling water system design, temperature changes and discharge time for the Morgantown SES on the Potomac Estuary.

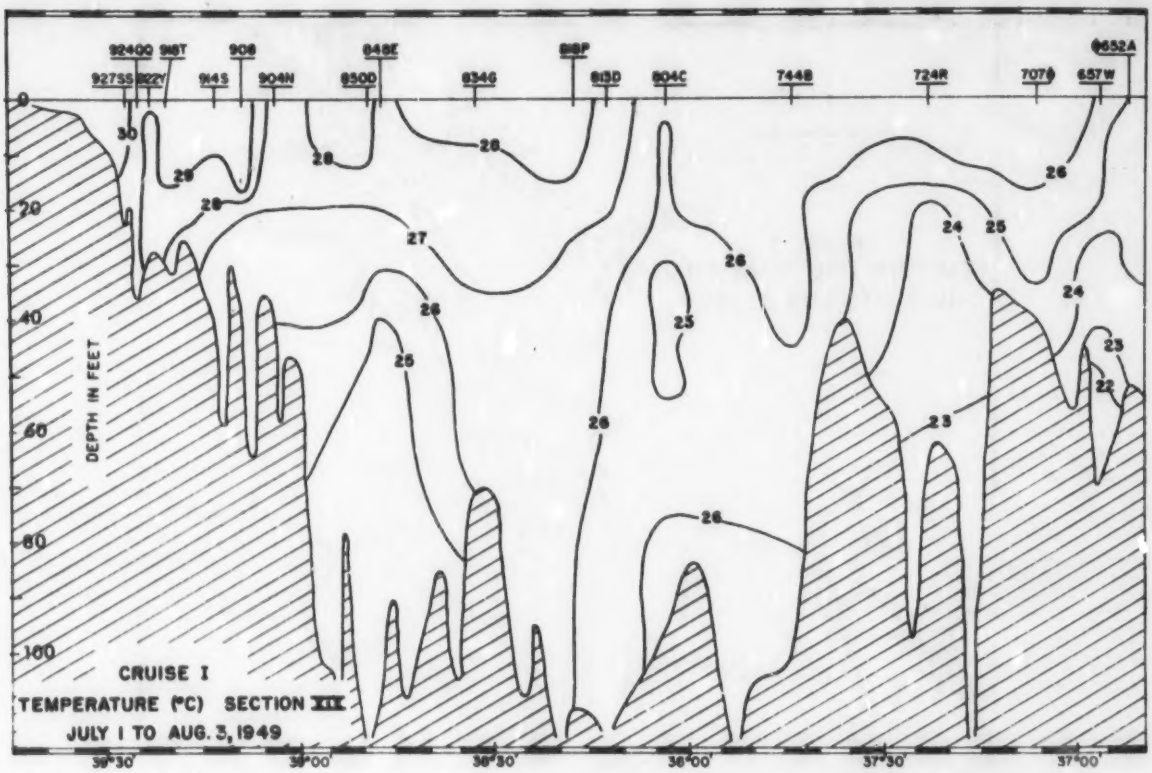


FIGURE 13.—Various temperature isotherms in a cross section of the Chesapeake Bay (from Whaley and Hopkins, 1952).

their southernmost limit of distribution on the east coast, e.g., the soft shell clam. Its southern distribution appears to be limited by high natural temperatures, and any relatively small heat addition in its shallow shelf zone habitat can therefore have detrimental effects (Kennedy and Mihursky, 1971).

It has been observed that below about 40 feet in depth the bay system between Annapolis and the mouth of the Rappahannock (Figure 14) tends to become deficient in oxygen during the summer, and as a result probably contains fewer organisms than surface waters. Waters from these cooler depths may be useful as an industrial cooling water supply in summer. A new nuclear SES is locating in the bay midsection (Figure 14, arrow) and will pump in a cooling water supply from a depth of 28 to 40 feet. This same installation will also have a short intake-discharge passage time (about 4 minutes) and will use sponge balls for cleaning condenser tubes instead of chlorine. A number of design decisions have been made that reflect a certain awareness of and response to environmental vulnerabilities and flexibilities.

The field of ecology is also gaining in sophistication by developing predictive models with regard to proposed environmental modifications. Figure 15 is one such thermal-biotic predictive model for an estuarine system developed for use in the Chesapeake Bay. The model presents optimal and sub-optimal summer temperature levels for the bay animal community.

Figure 16 presents a model that describes the flexible temperature zone existing for bay species for the various seasons. From the maximum allowable temperature elevation line (MATE—dotted line) one is able to predict the maximum increase in temperature that will still permit optimum functioning and production of the bay ecosystem throughout the year (Mihursky and others, 1974).

Biological data and analysis will continue to provide sound guidance to the establishment of proper water quality criteria and standards pertinent to thermal discharges. Coutant's (1972) recent review

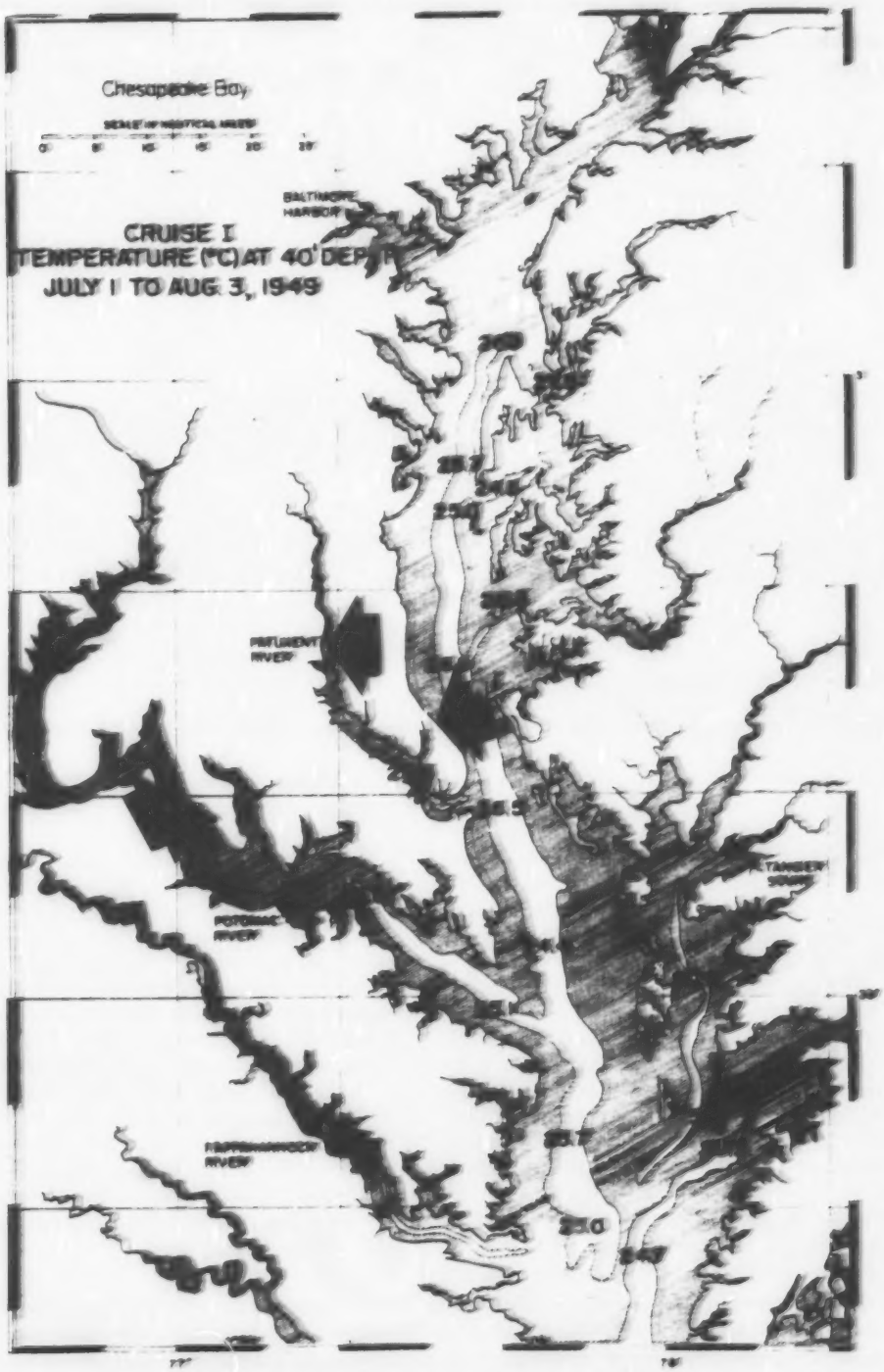


FIGURE 14.—Forty-foot depth areas (in white) in the Chesapeake Bay and existing water temperatures. Arrows indicate SES locations (from Hopkins and Whaley, 1952).

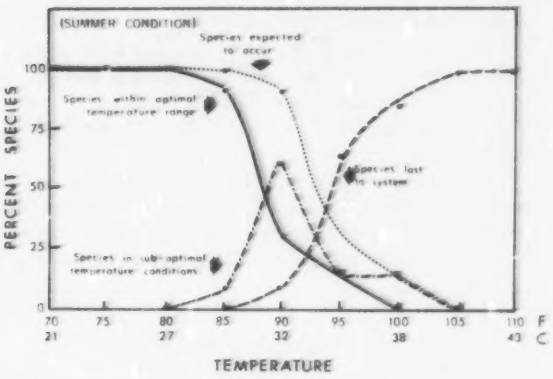


FIGURE 15.—Thermal-biotic predictive model for an estuarine system (summer condition).

entitled "Biological Aspects of Thermal Pollution II. Scientific Basis for Water Temperature Standards at Power Plants" is an excellent example of such guidance.

Another continuing and unfortunate trend is that the initiative for selecting SES sites is still residing with the electric utility industry. State and federal management and regulatory agencies are still responding to industry's initiatives that are often not based on natural resource interests. In addition, considerable reliance is still being placed upon industry's data, or analysis and interpretation by their consultants in describing "effects" and their "significance."

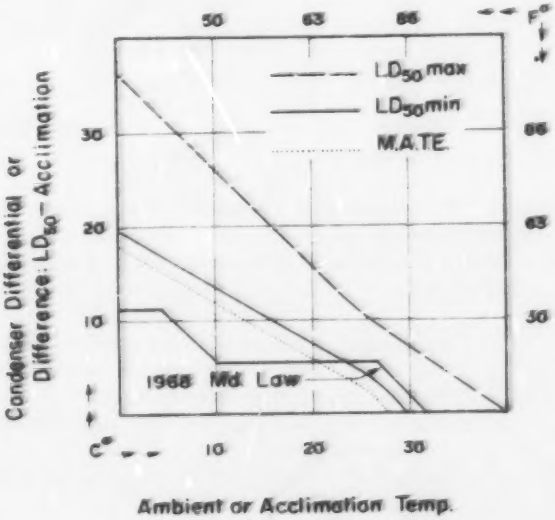


FIGURE 16.—Summary of laboratory TL_m testing on estuarine organisms. Individual lines have been omitted and only the extreme (minimum and maximum) TL_m slopes are plotted. The "old" and "new" (1968) Maryland temperature standards are also plotted. M.A.T.E. is the predicted maximum allowable temperature elevation permitted to protect estuarine species.

RECOMMENDATIONS—POLICY

Everyone now recognizes that we have had in the past, two important unwritten national policies with regard to energy and water. Namely, that both shall be abundant and cheap. It is quite clear that our growing inability to provide our human population with cheap and abundant energy and water is forcing changes in our conceptual and operational strategies.

- *National and regional energy policies must be established.* Obviously we must establish energy priorities and sound energy use policies. National and regional management strategies should dictate that we meet legitimate social objectives by means of least energy use pathways. Regional thermal loading should not exceed thresholds that cause unwanted natural resource or climatological responses.
- *The objective of achieving a quality environment in order to achieve a quality society should not be compromised.* Recent commentary that we cannot afford to maintain necessary environmental quality standards fails to incorporate all hidden costs and is an improper conclusion.
- *Federal and state management and regulatory agencies must maintain a high level of internal expertise in order to assess and evaluate actual or proposed environmental changes.* Reliance must not rest solely upon the resource user to design studies, gather, and evaluate data.
- *Initiative and guidance for siting and operation of SES must emit from agencies having national or regional responsibilities, and step by step methodologies must be followed in order to achieve siting and operating of SES with the best environmental fits.* The Water Working Group of the Committee on Power Plant Siting (1972) illustrated in a schematic fashion (Figure 17), and discussed in some detail, the types of procedures to follow. Their recommendations are still valid.

RECOMMENDATIONS—RESEARCH

It is quite clear that we must proceed to manage ourselves from an objective scientific basis, more so than ever before. Environmental costs and benefits are indeed social costs and benefits. Objective decisions must be based on quantitative data, with "all

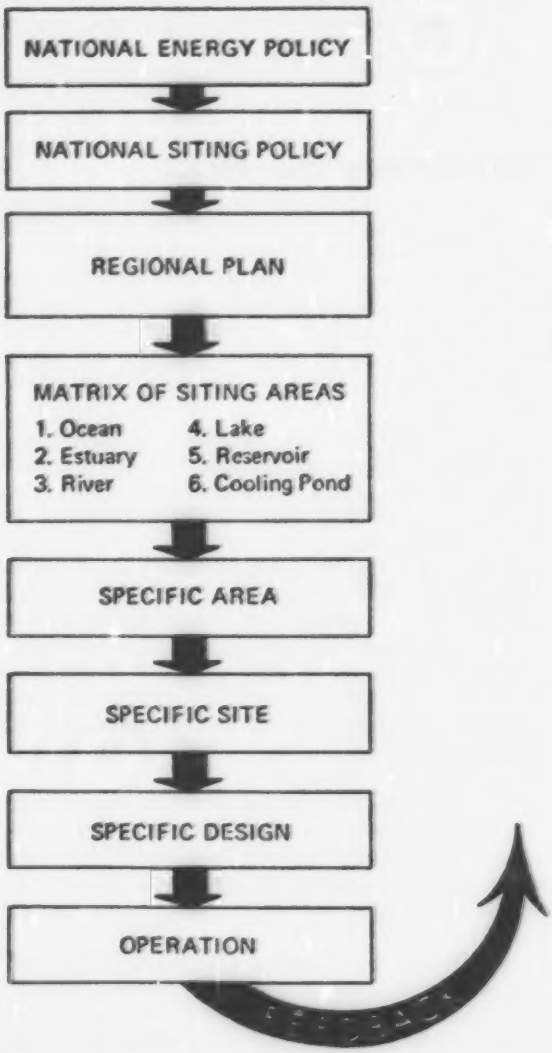


FIGURE 17.—Flow diagram for power plant siting considerations (after Committee on Power Plant Siting, 1972).

the cards on the table." Future generations should not resent our present decisions due to our lack of honest objectivity in meeting legitimate social goals.

• *Basic research activity must be maintained, e.g., the process important in estuarine systems must be understood.* In order to factor in proposed perturbations due to SES operations, a full quantitative understanding must be achieved as to how estuaries function.

• *Biogeographical mapping must be completed for estuarine systems.* Such mapping can provide dynamic regional impressions of priority resource characteristics. Lippson's (1973) recent atlas of the major natural resources of the Maryland portion of the Chesapeake Bay is an excellent example of one such effort.

• *Management and research dealing with thermal discharges should be based on natural estuarine biotic zones.* The Water Working Group of the Committee on Power Plant Siting (1972) proposed the following zones:

1. Canadian border to Cape Cod.
2. Cape Cod to Cape Hatteras.
3. Cape Hatteras to Ft. Lauderdale, Fla.
4. Fort Myers to the Mexican border.
5. Mexican border to Point Conception.
6. Point Conception to Canadian border.
7. Coast of Alaska—probably should be two or three zones.
8. Tropical islands and tip of Florida south of a line from Fort Lauderdale to Fort Myers.

• *A list of important species should be determined for each estuarine zone in order to establish priority of target species for which critical data are to be developed.* Important species must meet one or more of the following criteria:

1. Important as a commercial species.
2. Important as a recreational species.
3. Important in biological energy flow.
4. Present in large biomass.
5. Unique, e.g., for research, aesthetic value, endangered.

• *Quantitative data must be provided concerning population dynamics of these important estuarine species.* Information should at least include the following:

1. Quantitative estimates of numerical abundance, as well as location of various life history stages, from eggs to adult.
2. Estimates of natural mortality rates for each life history stage.
3. Longevity times for each life history stage and generation time (egg to egg) for each important species.
4. Minimum numbers of spawning stock required to produce the next generation at some desirable sustained yield.
5. Second order effects on population dynamics from any altered predator-prey, host-parasite, host-disease changes in the system.

- *It must be determined whether cropping rates from SES activity on these various life history stages are interfering with production of a desirable sustained yield of the important species.* SES site and operational specific, pumped-entrapment and pumped-entrainment studies, must be coupled with laboratory experimentation to assess what, if any, cropping rates may be assigned to specific SES operating sites and to specific operational conditions.
- *Quantitative biological responses to physical and chemical changes attributable to near and far-field discharge plume characteristics must be acquired.* Behavioral, growth, and reproductive responses of species must be determined.
- *The effects of entrainment and plume characteristics on biological energy flow in estuarine systems must be evaluated.* Basic information on who eats who and how much, i.e., bioconversion, must be developed. In the final analysis, from a management viewpoint, changes in species composition or relative abundance may not be as important as maintaining desirable quantities of energy flow into useful species.
- *Regional physiological-ecology facilities must be established to carry out much needed studies under controlled laboratory conditions.* Single variate and multi-variate experiments must be performed in order to assist in evaluating the effects of physical and chemical changes proposed by SES operations upon behavior, growth, and reproduction of important species. Such laboratory studies should also determine optimum and sub-optimum environmental conditions for a species.
- *The above developed estuarine field and laboratory data must be used to produce biostat models, e.g., predictions as to what conditions are to be maintained in order to produce desirable crops, i.e., sustained yields.* Although Goodyear (1973) has come under some criticism, his attempt to predict the effects of various SES on the Hudson River estuary upon striped bass yields (Table 2) was an excellent pioneering effort. He has conceptually pointed the way.
- *Quantitative biostat predictions must be converted to some economical equivalent to permit incorporation into regional and ecosystem input-output models in order to assist decision makers in establishing ecosystem strategies and objectives.* (Cumberland, 1966).

Table 2.—Electrical power generating technologies (after Anon., 1972)

Method of Generation	Heat Disc. to Cond. Cooling Water BTU/KWH	Expected % of Total Capacity Year 2000
PRESENT SYSTEMS		
Hydroelectric (Conventional & Pumped Storage)	0	5
Fossil Fuel	3,900	10–20
Shale Oil, Coal Gasification & Coal Liquification (new fossil fuel)	3,900	10–15
Internal Comb. Eng.	0	<1
Gas Turbine	0	<1
Topping G. T. w/Waste Heat Boiler		<1
Light Water Reactors	6,600	30–40
DEVELOPING SYSTEMS FOR THE SHORT TERM (1970–2000)		
Gas Cooled Reactors	4,800	10–20
Nuclear Breeders	4,500	10–15
Fuel Cells	0	<5
EGD	0	<5
MHD	0	<5
MHD Topping Cycles	1,700	<5
Geothermal		<1
DEVELOPING SYSTEMS FOR THE LONG TERM (AFTER 2000)		
Thermoelectricity		0
Thermionic		0
Fusion	small	0
Solar		<1

CONCLUSIONS

The tasks outlined above are substantial and costly; their completions however, will have important spin-off value to many other resource management and regulatory problems. Many of the major points made in the text have been made before. Indeed one gains the impression that everything has already been said that should or could be stated. The challenge is to affect priorities, procedures or policy, traditionally a difficult task for environmentally oriented interests in our society.

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EFFECTS OF THERMAL DISCHARGES UPON AQUATIC ORGANISMS IN ESTUARINE WATERS WITH DISCUSSION OF LIMITING FACTORS

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ABSTRACT

A descriptive summary of both thermal and nonthermal power plant effects is presented with an attempt to provide an insight into the total ecological impact of power generating stations operating in estuarine systems. Specific effects of thermal and other plant associated stresses are summarized for aquatic organisms exposed to a range of time and temperature exposures resulting from once-through cooling systems. This review presents specific summaries of representative case histories of thermal effects in east coast, gulf coast, and west coast estuarine systems with an attempt to identify regional characteristics that may influence the response of aquatic populations to thermal effluents.

INTRODUCTION

Considerable attention has been given to the effects of thermal elevations in the condenser cooling system upon aquatic organisms exposed to the discharges for once-through cooling systems. Certainly, much of this concern is justified on the basis that aquatic organisms are vulnerable to physiological shock caused by such exposures. Indeed, thermal deaths have occurred and short of outright death, considerable stress has been detected within surviving members of individual species populations. While we should attempt to keep thermal exposures to a minimum in terms of both amplitude and duration of exposure, other flow related influences should not be overlooked. Indeed, in attempting to reduce the effects of thermal exposures, many design and operational changes at once-through power systems have created new problems for aquatic organisms. My comments are brief and summary in scope. We can assume that our interests in protecting the fisheries populations adjacent to electric power generating systems require the consideration of those aquatic organisms that are of ecological significance to the survival of fisheries populations. Briefly then, I would like to discuss biological monitoring programs and the kinds and levels of effects that have been noted in connection with power generating stations operating within estuarine systems.

FREQUENCY OF DATA COLLECTION PROCESSES

Biological monitoring programs have been used for the past 10 to 12 years to assess the influence of thermal discharges upon surface waters used in the condenser cooling systems of both fossil and nuclear power plants. Initially, studies were limited in both biological scope and frequency, stimulating considerable confusion and debate over the value of individual data programs. Although such studies were intended to monitor effects from specific power plant systems, necessary plant operational fluxes were frequently omitted from data collection programs. Such operational data is relatively easily obtained but, due to the necessity of using power plant personnel with specific engineering expertise, it was often not included by aquatic scientists during either the formulative period in the data collection processes or the interpretable phase of biological data review.

Earlier studies of aquatic biological populations influenced by individual power stations were conducted by teams of specialists, on a quarterly or at best, bimonthly basis. Such studies were assumed to be sufficient to indicate significant effects, but they often resulted in the documentation of seasonal, temporal, and spatial fluxes of populations within each surface water system with such statistical variability from period to period as to make subsequent correlation with physical data exceedingly difficult, if not impossible, to make.

More recent biological monitoring programs have

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been conducted on a much more intensive basis. Data on daily fluctuations in vertical and horizontal stratification are now commonly collected for all major biological groups on a seasonal basis with the results that monthly data efforts reflect a tremendous range of technical skills and sampling techniques. These studies involve an increasing effort to conduct presiting data programs that can be used to avoid the location of power plants within areas of critical or high biological significance. Moreover, presiting data collection programs have the potential value of improving design criteria for minimizing biological impacts at appropriate sites.

The incorporation of intense presiting biological data programs to new power plant programs provides quantities of data spanning a longer number of years before thermal and other condenser system effects are initiated. The result of such programs is to provide much more confidence to the documentation of the normal biological distributions around a specific site. Annual pulses or fluxes in numbers of individuals of a given species are also much more readily disassociated from the effects of the combined influences of the condenser cooling systems of individual power plants. The following lists of levels of data and areas of potential effects represent common efforts of current estuarine thermal research projects.

WATER INTAKE AREA EFFECTS

The first engineered interface of a power plant with its surface cooling water supply is the water intake structure including, of course, screening hardware and associated structures. Design engineers currently expend both effort and ultimately considerable expense to control approach velocities to reduce the potential for hydraulic capture of both debris and fish. Although most new screen intake structures have velocities of 1 fps or less, the experimental basis for this constraint is based more upon the demonstrated fact that such velocities have much less impingement potential than higher velocities. Unfortunately, while these numbers are on a practical basis useful to design engineers as a general guide, the fact of life is that even at these relatively low design velocities, hydraulic capture of fish populations occurs on an all too frequent basis and the reduction or the solution of the problem is much more of an art than a science.

A more experienced applied biologist colleague of mine once offered a very useful observation to me on the occasion of his retirement from the faculty at our institution. His observation was, essentially, that the best explanation of natural events and incidents involving fish populations was that the fish as a biological group were quite prone to suicide. Since his retirement, I have found many a power plant engineer who agreed with him. An obvious explanation for the accumulation of fish at intake screening structures involves the fact that screening equipment does collect debris relatively efficiently and dead or dying fish are easily collected along with other debris at intake equipment. Obviously, not all fish at such screening equipment are there on the basis of chance. The attraction of fish to hydraulic flows is explained both physiologically and ecologically in terms of energy conservation. If fish are prone to suicide, they, like many other biological groups, do not waste energy looking for a food source when they can remain relatively stationary and just select appropriate food as it comes by. Even predator species can take advantage of the concentration of prey species in these current systems. The end result is, of course, the establishment of a relatively concentrated biological food chain within the area where these abnormal flow gradients occur for the system. Other aquatic organisms such as crabs, shrimp, and forage feeders can be found at intake systems of gulf and coastal system intake areas.

At those power stations where water quality is uniformly high and where approach velocities are not so high as to entrap and then impinge these organisms, no particular significance can be made for these accumulations. However, when the water withdrawn and used for cooling purposes periodically fluctuates to sub-optimum values for individual species, stressing conditions and, ultimately, death of concentrated populations in these areas occurs and the screening equipment must handle the removal and disposal of the bodies of these organisms. Such events as upwelling, seiching, and surface currents can also produce these events.

Unfortunately, many intake structures and areas have been built with such high velocities that exhaustion and physiological collapse by fish in front of the screening equipment occurs. The result is, of course, that such fish populations are highly vulnerable to additional and extraneous stresses that can cause an "incident" at the screening equipment.

Unfortunately, discharges of heat into intake areas, discharges of chlorine and other products required by the condenser cooling system for either fouling or corrosion control can also adversely influence the survival of relatively dense populations of fish in such intake areas. Solutions to these intake and screening equipment problems will require considerable research relative to the ability of fish to maintain both sustained and darting swimming

efforts in a mixed assemblage of species involving both predator and prey species. Age-class differences in endurance must also be considered in such experimental systems. Observations of plants where intake problems are relatively scarce, or at least less detectable, suggest that short, stubby cul-de-sac or funnel shaped intakes have considerable potential for the capture and impingement of fish. Such systems have very few areas where recuperation and resting by swimming organisms can occur. Flush shore intake systems have not been involved with fish impingement problems as frequently as have intake channel sites. Presumably, opportunities for bypassing screening equipment provide for the escape to lower velocity areas by swimming fish. Tidal and shoreline currents also act to carry fish away from screening surfaces in this area.

CONDENSER COOLING SYSTEM EFFECTS

The term "entrainment" has been borrowed from the hydraulics field and used to describe the combined experiences of planktonic organisms from the time of their first exposure to the intake pumps, through the condenser cooling system and subsequent mixing with receiving waters downstream from discharge structures or canals. A distinction is made between "pump entrainment" of planktonic organisms that are subsequently exposed to maximum thermal elevation, turbulence, sheer, and pressures, and "plume entrainment" or planktonic interaction with the thermal plume by organisms that have not experienced the combined experiences of the condenser system. Obviously, the experiences of these two types of entrainment are quite different and they should be distinguished because the temperature and time of exposure as well as turbulence, sheer, and other mechanical stresses are distinctly different for the two types of experiences. Research has shown strikingly different results from these two types of entrainment experiences. The term plankton refers to organisms that are at or near neutral buoyancy and thus, the term is more indicative of the relatively free floating character rather than taxonomic relationships between organisms composing the plankton. Thus, three major groups of planktonic organisms can be described, each with relatively different individual response and population susceptibility to the entrainment experience.

Phytoplankton

These microscopic algal cells are, by definition, always planktonic (Euplanktonic) and thus as primary producers of organic energy, they represent a highly important and vulnerable level for entrainment damage. Phytoplankters reproduce within minutes to hours and thus the recovery potential of these organisms is relatively high. That is, should destruction of a portion of the population occur due to either pump or plume entrainment damage, the species population has a relatively high reproductive potential for recovery within a few hours. Moreover, death of these algal cells does not change the nutriment value of the population since most aquatic predators do not distinguish between dead and living cells.

Experience in attempts to measure the stresses upon phytoplankton during exposures to the combined experiences in the condenser cooling system suggest that the response of phytoplankters is most related to the prevailing ambient water temperatures and the temperature rises (ΔT) of particular condenser cooling systems. That is, if death of living plankton occurs it is most predictable on the basis of seasonal high water temperatures, usually occuring only a few weeks or months during each year. At other times of the year the phytoplankton appear to be stimulated by the entrainment experience as indicated by increases in the rates of photosynthetic processes, chlorophyll levels, and absolute numbers of cells of individual species found in discharge and mixing areas (Warriner and Brehmer, 1966, Gurtz, 1973, Brooks, et al., 1974, Jensen, et al., 1974, Smith, et al., 1974).

The above effects should not be considered as necessarily beneficial to the aquatic population residing in a cooling water body. Numerous water bodies do not need such stimulation by living plankton populations and in some cases the destruction of phytoplankton can contribute to oxygen problems due to the BOD demands of the dead plankters downstream from the discharge areas. Thus, the significance of damage to this level of aquatic populations should be determined on a site specific basis.

Zooplankton

This term describes a very rich assemblage of invertebrates that are, in most cases, microscopic. Many zooplankters are truly planktonic, and only a few groups are consistently neutrally buoyant. Thus, effects of the entrainment experience at this level is likely to be much more species specific, and, in fact, current research appears to verify this assumption. Moreover, potential mechanical damage to these types of organisms is considerable, especially with larger crustacean forms of the zooplankton;

such damage has been found to be both size and species dependent.

Behavioral excursions of zooplankton from lower to upper water levels has been shown by Kelly, 1971, Kelly, et al., 1971, Kelly and Chadwick, 1971, Icanberry and Adams (1972), Davies and Jensen (1974) and others to bring these zooplankters into water volumes where they can be affected by both pump and plume entrainment experiences. Considerable variation has been found relative to the vulnerability of different life cycle stages of zooplankters to the effects of both thermal and mechanical damage; eggs, early naupliar stages, appear to be more resistent than larger, older and somewhat more physiologically complex stages. Moreover, prolongation of thermal exposures by residence within long discharge canals has been shown by Davies and Jensen (1974) to promote thermal damage to zooplankters. Sheer and mechanical turbulence of discharge structures may inflict physical damage on larger plankters. Little evaluation of zooplankters during turbulent plume mixing has been made. Research by Carpenter (1974) suggests that alterations in behavioral activities of microcrustacean zooplankters can result in decreases in the population downstream from once-through power plants. Depending on levels applied and individual toxicity of each species, chlorination activities can destroy all plankton organisms when and if used for the control of biofouling in the condenser system. Recirculated heat, as a control system, appears to achieve the same degree of damage.

Meroplankton

By definition, these transient plankton forms are only present for a brief period during which growth and development proceed to either a sessile or swimming juvenile stage, leading ultimately to either the sessile or nectonic adult form. Numerous invertebrates such as crabs, lobsters, shrimps, clams, oysters, and other taxonomic groups have meroplanktonic eggs and larvae. Most fish have meroplanktonic egg and larval stages (known as ichthyoplankton) that are present for a period of days to weeks following spawning activities. Thus, prevailing currents and tidal flows can bring these temporary plankton into contact with thermal plumes with effects that are not readily measured.

Moreover, entrainment damage of meroplankton stages can have considerable influence upon the populations of fishes and invertebrates well beyond those detected in the near field mixing area. These organisms are likely to have a reproductive potential considerably less than that of euplanktonic forms. Damage to these stages can influence the population structure of individual species and communities. Thus, the ecological significance of this type of planktonic entrainment within the condenser cooling system is rather obvious. Experience by biologists studying this problem suggests that considerable physical damage occurs with the rather delicate larval forms of both invertebrates and vertebrates. Egg stages appear to be less susceptible to such physical damage. Excessive turbulence and pressure such as cavitation tend to promote this type of damage. Indeed, some power stations have been reported to produce near total destruction of meroplankton while other stations seem to produce much less damage to the plankton. Current research and modeling of condenser cooling structures should reveal the reasons for these observed differences.

Obviously, the ecological significance of point source types of entrainment such as has been described above must be considered by the use of biological modeling that has, unfortunately, not been developed successfully at the present time. Thus, the ecological significance of these types of entrainment damage can only presently be approximated on the basis of percent of waters used for cooling versus total water available for the support of such planktonic stages. Special or peculiar concentrations of these stages such as clusters or patches can lead to disproportionate effects of entrainment damage upon the individual populations and thus, considerable sampling effort should be made of the near and far field areas to ascertain such distribution differences of individual power plants and plant sites. Such sampling efforts represent a relatively unusual and rather expensive effort.

DISCHARGE AREA EFFECTS

The geometry and site specific characteristics of the discharge area have, like the intake area, a highly plant specific impact on aquatic organisms. The decision to either rapidly mix thermal discharges into the receiving water body through such devices as momentum jets or submarine diffusers can cut the time of exposure to maximum thermal elevations, effectively reducing discharge effects, especially those affecting fish populations attracted into the discharge area.

Discharge canals have been shown to produce highly variable results in terms of impacts upon local aquatic populations. Effects of thermal exposures, cold shock, chlorination "incidents," and other adverse influences have been promoted by the use of long, low velocity discharge canals. These

effects have been shown at west coast, gulf coast, and east coast estuarine areas.

MIXING AREA EFFECTS

Considerable effort has been expended by hydrologists in an attempt to describe the dimension of thermal effluent mixing areas. These modeling efforts provide an existing and exceedingly useful series of time-temperature distributions with information relative to changes in these plumes caused by tidal and other natural currents. Their high value and significance to biologists who are attempting to assess the ecological effects and interactions of these effluents in surface waters is obvious. In fact, it would be quite impossible to accurately model the stresses of near field and far field distributions of waste heat without such predictive hydraulic and mathematical modeling research.

Measurements of these downstream effects from the combined pump entrainment and plume entrainment experience suggest that some of these effects are so subtle as to not be readily detected by existing field population census techniques. Certainly some avoidance of and attraction to the thermal plume has been historically seen by many workers.

SUMMARIES OF REPRESENTATIVE CASE HISTORIES OF THERMAL EFFECTS IN ESTUARINE AREAS

The estuarine environment is an exceedingly complex ecological system. Indigenous finfish, migratory finfish, anadromous species, shellfish, and such crustacea as crabs and shrimp depend upon the estuaries for at least some part of their life cycles. The economic importance of specific fisheries in the above categories can be considerable.

Large tidal bodies of water, such as the Chesapeake Bay, Galveston Bay, and others, could, theoretically, offer considerable quantities of cooling waters if the aquatic populations of each estuarine system could be protected from a uniform and complete thermal elevation throughout the system. Again, considerations of specific sites must consider the amount of "new water" passing by a given site and the relative quantity of such waters needed for cooling waters by particular plants. Behavioral and reproductive phenomena such as schooling, spawning, and nursery areas must be protected from thermal elevations. In such systems, mixing of discharge effluents into tidal waters can reduce the effective temperature rise (ΔT) to only one or two degrees above ambient levels. Caution must be given to intake and discharge levels so as to withdraw only the least populated water levels. When the cooler and more saline bottom waters are used as a cooling water source, considerable research should precede plans for the discharge of the thermally elevated, saltier waters. Such discharges have been shown to sink to a mid-depth in response to combined thermal-saline density factors. When and if this occurs, the influence upon local populations must be predictable before alternative discharge plans are rejected.

Moreover, in smaller bays and estuaries, withdrawal of large fractions of water have altered circulation patterns in local areas (Jensen, 1974). As mentioned above, such influences can change behavioral patterns with local populations of fishes and invertebrates. Tidal influences in terms of the direction of discharge plumes complicate the above predictions to the extent that hydraulic models are often used to simulate flow patterns. Such an application has been made in the James River estuary model located at the U.S. Corps of Engineers Waterways Experiment Station in Vicksburg, Miss. The model has a horizontal scale of 1:1000 and a vertical scale of 1:100. The time scale is 1:100 so that one day in the prototype occurs in 14.4 minutes time in the model. The proposed discharge of the Virginia Electric and Power Company Surry Nuclear Power Station has been simulated in the model, and temperature measurements have been recorded along various transects across the model through many tidal cycles and under different freshwater inputs. Since it was not possible to simulate all conditions in the model, theoretical conditions were applied, and the empirical data were thereby adjusted to conditions expected in the prototype. The predicted distribution of excess heat in the estuary will be verified in the James River estuary, after the Surry Power Plant begins operation dur. . the spring of 1973.

Another such model is being planned for the entire Chesapeake Bay. Several hydraulic models of limited areas of the bay and its tidal arms have been built by the Alden Research Laboratory of the Worcester Polytechnic Institute in Worcester, Mass., and are used to predict the physical behavior of thermal discharges. A similar model of the San Francisco Bay and Sacramento-San Joaquin Delta has been used to simulate thermal distribution at various power-plant sites in northern California.

The control of biofouling in tidal systems is considerably more difficult than in freshwater systems. The application of wide-spectrum biocides for such fouling control, both within the intake system as well as the condenser system, must be made with caution to avoid killing fish and invertebrates

residing in discharge canals and receiving waters. Excessive chlorination and use of widely active compounds such as copper sulfate have lead to dramatic incidents that have mistakenly been reported as thermal kills.

As mentioned previously, the temperate estuarine populations of southern latitude species are often living close to their upper thermal tolerances during summer periods. These species have much narrower thermal tolerance ranges than northern populations of the same species which can withstand wider thermal fluctuations. Thus, if an appreciable heat load is introduced into a mid-latitude estuary, it must be recognized that the local thermal distribution might actually favor the growth of more southerly species (or subspecies) in limited areas. One difficulty with such changes is that it is likely that some disagreement will occur between local biologists as to what constitutes a "desired species." A conservative ecologist might contend that only those species that exist normally in the outfall area are the desired ones, while other ecologists might be willing to settle for a slightly different fauna and flora in a limited area.

Studies made at the Chalk Point Generating Station on the Patuxent River estuary in Maryland before and after the operation of the power plant showed that local populations of striped bass increased while concentrations of white catfish and hogchokers declined. White perch populations remained constant during the study. Total gillnet catches by commercial gear were approximately the same at the station nearest the power plant and increased at the two other stations farther downstream. Sport fishing in the area has increased in winter months (Maryland Department of Natural Resources, 1969).

Studies of the oyster *Crassostrea virginica* on beds within 1,200 feet of the discharge canal at the Chalk Point plant showed no major effects on the growth, condition, and gonadal development as a result of plant operation (Rosenberg, 1968, Patrick, 1968). Invertebrates harmful to the oyster, the oyster crab *Pinnotheres ostcrum*, and the worm *Polydora* were no more common in 1965–67 after the plant went into operation than in 1962–63. The accumulation of copper in oyster tissues was also reported from beds in the vicinity of the Chalk Point plant. Subsequent investigations showed that the copper concentrations in water upstream from the power station were 1.97 parts per billion, while that in the outfall was 3.01 parts per billion (Patrick, 1968). This apparently is not common to power plant operation in estuarine areas, but was the result of improper design and metallurgy in the condenser tubing. Cory and Nauman (1969) reported that the number of fouling organisms, including barnacles, increased at the locations influenced by the discharge of the Chalk Point station, decreased upriver from the power plant, and that the increase was associated with the warmer effluent waters.

Studies by Patrick (1968) on the Chalk Point station indicated a well-diversified flora throughout the area influenced by the thermal discharge in August, 1968. Nutrient additions upriver from the plant were reported by Patrick to complicate the assessment of the plant's effects on the standing crop of algae, though the cyclic seasonal patterns observed before the plant went into operation were lost at stations above and below the discharge canal.

Morgan (1969) studied the effect of temperature and chlorination procedures on the passage of phytoplankton through the condensers at the Chalk Point Plant and found that when the effluent temperatures were between 88.7 and 92.4° F (chlorination levels were not known), photosynthetic capacity was reduced by 68.6 to 94.3 percent. During colder seasons, photosynthesis was reduced by as much as 85.7 percent. However, Morgan (1969), Mihursky (1967), and others believe that chlorination procedures were responsible for much of this reduction.

Patrick (1968) found no significant difference in the composition of the zooplankton and/or phytoplankton at the Chalk Point station at similar times of the years 1963, 1967, and 1968.

Two microscopic crustacea, the copepods *Acartia tonsa* and *Eurytemora affinis*, were the dominant species, and *Acartia tonsa* standing crops were greater during the summers after the Chalk Point station began operating. Two jellyfish, *Mnemiopsis leidyi* (a comb jelly ctenophore) and *Cryasora quinquecirrha* (a sea nettle) were more prevalent before the plant began operating. Mihursky (1967) reported that thermal changes were responsible for this decline.

Warriner and Brehmer (1966) studied the effects of condenser discharge water on the benthic invertebrates in the York River estuary at the Yorktown Generating Station of Virginia Electric and Power Company. Community composition and abundance were affected over a distance of 980 to 1,300 feet from the discharge canal. All sampling stations, including the controls, showed a marked seasonal change in abundance, with a minimum in summer and a maximum in winter. The lowest diversity of species was found in a small area within 980 feet of the discharge, and this was interpreted by the authors to be an indication of stress on the benthic community in which only the more thermally tolerant species could survive.

Studies with a laboratory heat exchanger using natural York River water without chlorination showed that primary productivity of natural phytoplankton was depressed by a 10.1° F increase in water temperature when the ambient temperature was 59 to 68° F. A temperature rise of 6.3° F was sufficient to depress production when the ambient summer water temperature was 80° F. In cold weather, productivity was enhanced after passage through the exchanger (Warriner and Brehmer, 1966).

Thermal studies at a power plant at Turkey Point, a unique tropical area in South Biscayne Bay, Fla., have been reported by Tabb and Roessler (1970), Reeve and Cooper (1970), and Lackey and Lackey (1972). The benthic macroalgae *Acetabularia crenulata* and *Batophora oerstedi* were the only species observed at the mouth of the discharge canal during the period of February to September, 1969. The number of species of macroalgae increased at increasing distances from the discharge canal out into the Biscayne Bay. The stations nearest the canal mouth had the lowest numbers of species and thus the lowest diversity index (Tabb and Roessler, 1970). However, these reductions in benthic algae have been suggested to be due to the combined effects of dredging and construction of the power plant canal system along with the hydraulic scour that the discharge canal system imposed upon the areas of Biscayne Bay immediately adjacent to the plant site.

In September 1968, turtle grass, *Thalassia testudinum*, was reported to be killed over a 30–35 acre area which had apparently increased to 50 acres a year later. Benthic invertebrates and fish populations associated with the turtle grass and macroalgae populations were also reported to show decreased numbers in an area of 170 acres surrounding the discharge canal. An unspecified number of dead fish were reported to have been associated with the impact area in June of 1969.

Studies by Tabb and Roessler (1970) have suggested that these effects were primarily due to the thermal effluent from the Turkey Point Power Plant. However, unusually low salinities (16–17 ppt) and relatively high copper concentrations (15 mg/l) were also detected in waters with temperatures of 91 to 95° F (Lackey and Lackey, 1972). Such low salinities for the area (normal summer salinities are 27–33 ppt) coupled with the toxic levels of copper could have been partially responsible for the reported fish kill.

Moreover, the presence of such levels of copper could also account for the reductions in benthic grasses and their associated animal populations, as noted above. In the absence of more definitive data, however, such conclusions are speculative. Recent observations by Lackey and Lackey, 1972 suggest a recovery of the impacted area in the discharge canal and adjacent Biscayne Bay areas since the observations of earlier workers in 1968. Because of the tropical and relatively shallow nature of the Biscayne Bay, these ecological effects may suggest the types of effects that can occur in such estuarine systems.

Research on the thermal impact of a power generating station on Galveston Bay, Tex., was reported by Strawn and Gallaway (1970). Seasonal abundance, distribution, and growth of commercially important crustaceans were investigated. Temperature, conductivity, dissolved oxygen levels, pH, and biological samples of blue crabs, *Callinectes sapidus*, white shrimp, *Penaeus setiferus*, and brown shrimp, *Penaeus aztecus*, were taken once a month through 1968 and 1969. Collection stations were in and around the discharge canal of the power plant. The impact of the thermal effluent upon the above species was related, significantly, to the season, the relative abundance of each species, thermal tolerance, and thermal preference of each species studied. Blue crab populations appeared to be beneficially influenced by the power-plant activities (thermal increases and circulation improvements caused by pumping activities). White shrimp populations appeared to show both detrimental as well as beneficial effects, but the overall effect was judged by the authors to be beneficial. Brown shrimp were adversely affected in a limited area of the Galveston Bay surrounding the power plant (Strawn and Gallaway, 1974).

A study of the thermal impact of a Pacific Coast generating station at Morro Bay was reported by North (1968). Results of studies of the discharge canal and the coastal zone immediately adjacent to the power station indicated that seaweeds were almost completely eliminated from the discharge canal, while in a transition region beyond the canal, seven algal species of a total of 20 species in normal, non-thermally influenced areas were found. The transition area was fished rather intensively, and North suggests that schools of grazing Opaleye (*Girella migricans*) and various invertebrates account for some of this reduction. Thus, the marine flora of Morro Bay appears to be much more thermally sensitive than the fauna and the impact of the Morro plant effluent on the seaweeds might be explained by the thermal sensitivity of reproductive cells in association with relatively heavy grazing by fish and invertebrates within the area.

Mitchell and North (1971) examined the tempera-

ture and time of contact of marine plankton which were passed through the cooling water systems of two Southern California Edison Generating Stations located on the Pacific coast. Sampling at intake and discharge structures and subsequent incubation on site at the San Onofre and Huntington Beach Generating Stations simulated temperature time exposure met by plankters passing through the condenser system and traversing the discharge and mixing areas. Typical zooplankton mortality ranged from 12.7 to 28.4 percent with the high mortalities due to sampling error introduced during sample examination. The copepods *Acartia tonsa*, *Euterpe acutifrons*, *Corycaeus affinis*, and *Oithona helgolandica* and the mysid shrimps represented nearly all of the mortalities. Smaller soft-bodied invertebrates (polychaete larvae, *Sagitta* sp.) and protozoans showed little effects of passage. Analysis of carbon-14 and chlorophyll studied of phytoplankton populations passing through the condenser cooling system suggest that little damage to the populations occurred as evidenced by comparisons of ^{14}C uptake rates and chlorophyll *a*, phaeophytin *a* levels after a standard incubation-culture procedure of intake and discharge samples collected from the two generating stations. Some evidence of phytoplankton stimulation in discharge samples was noted during these studies and normal chlorination procedures resulted in obvious damage in the plankton populations collected in the discharge area during the chlorination period.

Icanberry and Adams (1972) have described the survival of zooplankton after passage through the cooling water systems of four California coastal power plants. A statistically significant increase in discharge mortalities of less than 11 percent compared to intake mortalities was found at all plants, suggesting average overall survival of approximately 90 percent. A statistically significant linear relationship was noted between the discharge temperatures and percent mortality in all four of the power plants examined. Twenty-four hour delayed mortality did not occur when intake and discharge samples were held at ambient intake water temperatures. Considerable mortality occurred when discharge samples of zooplankton were held at discharge temperatures for periods up to 24 hours of continuous exposure. Immature zooplankton stages exhibited increased mortality only after the first six hours, followed by adult copepods which died between 12- and 24-hour periods. Soft bodied invertebrate larvae were resistant to these combined effects of temperature and time of exposure. Surveys of actual temperatures occurring around the discharges of these four power plants revealed that these time and temperature conditions (discharge temperatures lasting 12–24 hours) do not occur due to the mixing and dilution of the thermal discharges with cooler Pacific coast waters. Thus, this research suggests that the very small increase in mortality (approximately 11 percent) due to passage through the cooling water system of these four power plants does not (in all probability) significantly affect the zooplankton populations of the Pacific Ocean in the areas surrounding the power plants examined by these researchers.

Extensive research has been underway over the past five years to evaluate the impact of once-through cooling systems of power plants located within the Sacramento-San Joaquin Delta area under the sponsorship of Pacific Gas and Electric Company. Field studies of the temporal and spatial distributions of thermal effluents of the Pittsburg and Contra Costa Power Plants in the central delta area have been supplemented by biological sampling in and out of the thermal plumes to locate populations of striped bass (*Morone saxatilis*), king salmon (*Oncorhynchus tshawytscha*), and other fish as well as fish food organisms such as the opossum shrimp *Neomysis awatschensis* (Adams, 1969, Adams and Doyle, 1971, Chadwick, 1971, Hair, 1971, Kelly, 1971, Wickmire and Stevens, 1971, Kelly et al. 1971, Kelly and Chadwick, 1971, Orsi, 1971, Rogers and Stevens, 1971, Gritz and Stevens, 1971, and Gritz, 1971). Distribution of young striped bass indicated that densities were always greatest at mid-depth and bottom as contrasted to surface areas in stratified areas of the delta. Intensity of stratification fluctuated with the stage of tides and size of fish. Small bass less than 9 mm were higher than larger fish and densities increased at all depths during flood tide. Lateral distribution varied but densities were lowest in surface and mid-depths of the Pittsburg thermal plume suggesting preference for the cooler bottom areas in the vicinity of the thermal effluent.

Further studies on fish distribution within the thermal plume of Pittsburg (Gritz, 1971) have revealed that striped bass, splittail, carp, white catfish, American shad, Sacramento western sucker and Sacramento blackfish were more abundant within the thermal plume of the plant than in control areas of ambient water temperature but equivalent habitat type. Stomach contents of striped bass suggest that the importance of the opossum shrimp *Neomysis awatschensis* diminished and the importance of fishes (including small king salmon) increased with striped bass size (Gritz, 1971). Unfortunately, these studies did not distinguish between increased predator concentration (striped

bass) within the thermal plume and physiological stress of king salmon which increased their vulnerability to predators as was suggested by Coutant, who described similar reactions within a thermal plume discharged into the Columbia River (Coutant, 1969). In a laboratory study, Kelly and Chadwick (1971), examined the tolerance of young striped bass in the size range of 5 to 38 millimeters in length. The LD_{50} for striped bass held for 48 hours ranged from 86 to 91° F with variations within this range not related to either acclimation temperature or size of fish. Instantaneous temperature increases (0 to 6 minutes duration) followed by return to ambient temperature resulted in little mortality until the maximum temperature approached 90° F. Below this temperature instantaneous increases of up to 18° F caused little mortality. However, loss of equilibrium was often noted at temperatures above 85° F.

By contrast to the distribution food habits and thermal response of striped bass, Gritz and Stevens (1971), studied the distribution of king salmon in relation to the thermal plume of the Pittsburg station. Occurrence of this salmon was primarily at the surface (in contrast to the location of striped bass at lower depths). Numbers of king salmon decreased from the north shore to the power plant on the south shore. Numbers of salmon caught in the plume of warm water discharged from the plant were significantly lower than numbers caught at ambient water temperature. Catches of marked hatchery-reared salmon released upstream suggest that these young king salmon migrate rapidly through the section of the estuary influenced by the thermal discharges of the Pittsburg plant. Gritz (1971) suggested that some of these salmon might be more vulnerable to predation by the increased number of larger (>16 inches) striped bass residing in the thermal plume. Orsi (1971) studied the thermal tolerances and thermal shock of king salmon. Rapid temperature rises within the limits of an 18° F increase and a 0–6 minute exposure period did not cause mortality until the acclimation temperature exceeded a temperature between 60 to 65° F. The ability of young salmon to withstand short exposures to relatively high temperature improved as acclimation temperatures were elevated. Exposure time was crucial to survival at 83° F with all fish surviving at 0–2 minute exposures to 83° F and only half the test fish surviving at exposure periods of 4–6 minutes.

The opossum shrimp *Neomysis awatschensis* has been shown to be an important food source for game species of fish in the Sacramento-San Joaquin Delta. The distribution of these mysid shrimp has been shown by Kelly et al. (1971) to be influenced by light, tidal stage, and water velocity. During the daylight period, density of *Neomysis* population increased with depth and lateral densities indicating little ability to avoid being carried by intake and discharge flows in the vicinity of the Pittsburg plant (Kelly et al., 1971). The mortality of *N. awatschensis* caused by passage through the Pittsburg piant was determined by Kelly (1971) from comparisons of live and dead *Neomysis* at the plant's intake and outlet. Observed mortalities correlated with the water temperature of the discharge (less than 10 percent at temperatures of 80–86° F compared to approximately 65 percent at temperatures approaching 90° F). Those *Neomysis* surviving higher temperatures showed no evidence of delayed mortality when held under laboratory conditions for up to 36 hours.

These mortalities were similar to those induced by Hair (1971) under laboratory conditions in which the upper lethal temperature of adult *Neomysis awatschensis* was found to be within the range of 75.6 to 77.8° F under conditions of 48-hour static bioassay. Tolerances to rapid laboratory exposures decreased as acclimation temperatures increased but this species resisted temperature elevations of up to 25° F provided the ultimate temperature did not reach 87° F. Temperature rises above 25° F caused significant mortality even though the upper temperature did not reach 87° F. As has been shown with numerous other aquatic organisms, survival decreased rapidly with increased exposure time at temperatures approaching the lethal temperature for these mysid shrimp.

In summary, these excellent field and laboratory studies of ecologically significant aquatic organisms in the Sacramento-San Joaquin Delta have revealed both techniques and information that can be used to evaluate the impact of similar industrial operations in other estuarine systems. These studies have shown no significant adverse effects upon aquatic organisms in the Sacramento-San Joaquin estuarine system. Volumes of water used for cooling purposes constitute but a small fraction of tidal and river flow in the Sacramento-San Joaquin Delta area at Pittsburg. Consequently, thermal elevations (above demonstrated upper lethal levels for important aquatic organisms) occur over a relatively small area and for a relatively short period of time. Thus, consideration of these physical and biological factors should permit the siting, design, and operation of power plants in similar systems—where the volumes of cooling water are sufficient to preclude adverse local or system-wide impacts.

Lauer et al. (1974) have studied the response of

aquatic organisms in the Hudson River at Indian Point from 1971 through 1974. An upper area of the Hudson River estuary between Newburgh and Yonkers, N.Y., was sampled in order to establish the kinds, numbers, and seasonal fluctuations in aquatic organisms residing within this section of the estuary. In these studies emphasis was placed upon estimating the effects of both pumped and plume entrainment of planktonic organisms during both day and night sampling periods.

The rated thermal capacities of the combined three units at the Indian Point Station, was approximately 15° F during these studies. Laboratory studies of bacterial decomposers indicated that the above thermal exposures did not decrease populations except during periods of intermittent chlorination when decreases in discharge samples were noted. Primary producers indicated variable degrees of effect during similar and varying thermal exposures above ambient temperatures suggesting that seasonally variable populations of algae respond with increases, decreases, and relatively little change in rates of primary production as measured by ^{14}C uptake and algal biomass. During periods when discharge rates were depressed over intake rates, recovery of populations as measured by restoration of intake rates was noted. Chlorination, when it occurred, always reduced primary production rates for algal populations entrained into the condenser cooling units. No population shifts from the predominant diatom populations to any other algal group within the Hudson River in the study area were observed.

Laboratory studies of zooplankton populations suggested that calanoid copepod populations might experience some mortality at the rated ΔT of 15° F. Unfortunately, during these studies, discharge temperatures did not reach design levels and field verification of these laboratory results was not possible. Some degree of stratification of zooplankton was noted in the area of thermal influence by the Indian Point plant, but both species lists and abundance of river populations of zooplankton were similar, suggesting that the combined thermal and chlorination effects that occurred within the condenser cooling system were not affecting populations within the Hudson River in a significant way.

Laboratory studies of the dominant zooplankters at Indian Point (*Gammarus* sp., *Neomysis americana*, and *Monoculodes edwardsi*) suggested that a 15° F ΔT during summer ambient water temperatures would result in 50 percent or greater mortality of entrained *N. americana* while the other two species would not suffer mortalities as a result of the entrainment experience. Actual mortality due to entrainment was subsequently found to be 54 percent. All three species showed diel periodicity with higher abundances at night. *Gammarus* sp. occurred on a year round basis at Indian Point while *N. americana* occurred primarily during summer periods. *M. edwardsi* was a year-round resident except for early summer periods when it was not detected in the area. Although laboratory studies of the design ΔT of 15° F suggested no direct mortality would occur to *Gammarus* sp., direct measurement of discharge samples of entrained animals indicated a small but statistically significant mortality had occurred with this species. Chlorination levels during daytime periods did not produce statistically significant effects due to the low densities of these macrozooplankton forms. At higher nighttime densities, mortality was approximately 40 percent of entrained organisms.

Results of studies of egg and larval fish entrained into the Indian Point Plant were variable as to species, life stage, and plant operational features such as number of cooling water pumps in operation during sampling periods. Only six of the 50 species of fish occurring in the Indian Point area were actually represented in the ichthyoplankton entrained into the condenser cooling system. These were, in order of decreasing abundance: anchovy, alewife, and blueback herrings, striped bass, white perch, and tomcod. Most of the anchovy and clupeid larvae were dead in both intake and discharge canal samples. Striped bass were too sparse to permit statistical evaluation of entrainment effects.

Jensen et al. (1974) studied the thermal response of aquatic organisms in a small mid-Atlantic estuary in Delaware just south of the confluence of the Delaware River estuary with the Atlantic Ocean. The Indian River Plant is situated midway between the freshwater and saltwater boundaries of a small estuary east of Millsboro, Del. Cooling water at 148,000 gpm is elevated an average of 12° F and rejoins the Indian River estuary 1–3 hours later via a 2 mile discharge canal. Temperatures at the mouth of the canal are typically 5° F above ambient and are reduced to about 1° F above ambient within about two miles downstream of the mouth.

Chemical data collected in the vicinity of the plant suggests generally high water quality; dissolved oxygen levels, for example, never fall below 5.00 mg/l at the surface nor below 3 mg/l near the bottom. Diverse flow and fauna inhabiting this region of the estuary reflect both high water quality as well as the strong salinity gradient existing along the length of the estuary.

Destruction of algal cells during passage through the condenser system was consistently apparent

during periods of chlorination (30 min. duration, 2–3 times daily), but was never observed in the absence of chlorination. Algal production rates measured at the discharge of the power plant were depressed due to temperature elevations for approximately four months of the year when ambient temperatures were about 71.6° F, although there was no evidence of lowered production rates at any distance from the discharge canal. During the cooler periods, (eight months), temperature elevations at the plant discharge resulted in up to two-fold stimulation of production rates and up to 20 percent increases approximately ½ mile downstream from the mouth of the discharge canal.

Little effect on the zooplankton behavior or population distribution could be attributed to the operation of the Indian River Plant. This lack of influence was presumably related to the average thermal elevation of only 10.8° F and the less than two minute travel time through the plant. It was concluded that the naturally wide range of salinity in the vicinity of the plant (2.2–19 ppt) was more influential to zooplankton ecology in this estuary than direct effects of thermal discharges from the Indian River Plant. Little change in mortality of zooplankton was observed throughout the entire seasonal range of ambient intake temperatures, even during periods of chlorination, which produced up to 0.5 mg/l free residual chlorine as measured in the discharge canal.

During the summer, however, prolonged contact with the thermal effluent resulted in a decrease in population densities of zooplankton passing down the discharge canal. By contrast, short-term intake-discharge evaluations to the same temperatures during passage through the condenser cooling system showed no die-off of zooplankton. Other factors not detected in these studies resulted in a decrease in discharge canal populations. In spite of these reductions, zooplankton populations in the receiving waters of the Indian River estuary did not appear to be affected by these losses.

The distribution of benthic invertebrates was shown to be associated with the large salinity gradient (0–22 ppt) within the study area of approximately 6.8 miles. Sediment temperatures were highest in the discharge canal and decreased to ambient temperatures through the mixing zone. Effects from the thermal discharges were limited to the discharge canal and the confluence point of the canal with the Indian River.

The upper Indian River estuary supports a large fishery biomass in the form of forage species. The estuary is also essential as a spawning and nursery area for game and commercially important species of fish. Undoubtedly, the power plant has some effects on the distribution of resident fishes in the estuary, but this would seem to be in a rather small, well-defined area within and adjacent to the discharge canal from the plant. These distributional effects appear to be restricted to the summer months when ambient water temperatures reach the seasonal and annual maxima. At other periods, the plant did not appear to seriously affect the survival, distribution, or well-being of any of the native or anadromous species residing within the estuary.

SUMMARY AND CONCLUSIONS

The rapid reduction of excess temperatures near existing thermal discharges into relatively large estuarine waters is largely a result of dilution rather than heat dissipation to the atmosphere. The spatial distribution curves for heated discharges can be shown to be directly related to the momentum of the discharge volume. In large, natural surface waters such as the Chesapeake Bay, it can be shown that such momentum jet discharges offer considerable advantages in terms of thermal decay curves. Thermal losses of waste heat to the atmosphere from such large bodies of water involve rather large surface areas at relatively small temperature increases (5–10 percent of original ΔT).

With the possible exception of tropical waters, the location of power-generating stations on large estuaries and open coastal locations appears to provide the relatively large volumes of water needed for modern once-through generating plants without producing serious damage to the biota of such areas. Ecological impacts can be minimized by careful siting, design, and operation so as to reduce temperature elevation and duration of aquatic organisms to thermal effluents. Momentum mixing of the heated discharge waters into receiving waters appears to rapidly reduce the temperatures to only a fraction of the original thermal rise. Such temperature reductions, within a few minutes after the passage through the cooling water condenser system, would also appear to minimize the effects of entrainment upon planktonic forms residing in surface waters used for once-through cooling.

RESEARCH NEEDS—THERMAL EFFECTS

Physical Mixing Process

1. Knowledge of buoyant jet diffusion is nearly adequate for the design of thermal outfalls, including multiple port diffusers, to achieve a prescribed initial jet dilution and mixing plume. Further

research is needed to fully understand line sources and to determine how well multiple jet diffusers may be represented by line sources.

2. Research is needed to develop better methods for predicting the size and shape of heated effluent mixing zones that are developed at the end of the initial jet-mixing stage. Research is also needed (in close concert with the above dimensional data) to understand the phenomena of lateral spreading caused by density differences between the thermal plume and receiving waters.

3. In coastal waters, submerged diffusion structures are not yet in use, and some problems of large single jets, such as the behavior of a buoyant, surface jet injected into a cross-current, need special study. The impact of potential scouring of bottom areas adjacent to such momentum discharges is also needed.

Heat Dissipation Processes

1. More research is needed to establish the natural temperature variations of future receiving waters, especially large water bodies such as the Chesapeake Bay. Such information pertinent to diurnal and seasonal temperature fluctuations is essential for the prediction and assessment of the relative impact of proposed thermal discharges.

2. As more information becomes available on the biological responses to thermal discharges in terms of both thermal amplitude and duration relationships, as well as rapid rates of temperature change, improvements will be needed in methods for predicting these characteristics of thermal discharges relative to short-term fluctuations in power demand, meteorological conditions, and operations of auxillary cooling devices.

3. More effort is needed to evaluate and verify temperature predictions based on hydraulic models of thermal discharges, particularly models of large prototype receiving waters in which surface cooling processes are not negligible and are generally represented inadequately.

4. Relative to item 3, more work is needed in developing techniques for computer simulation of thermal discharges in three dimensions, taking into account all the effects of momentum, entrainment, buoyancy, surface cooling, wind, coriolis forces, and other factors affecting receiving water behavior.

Biological Processes

1. Both field and laboratory research is needed concerning the biological response to time-spatial and thermal amplitude levels characteristic of situations involving once-through cooling in surface waters. Unfortunately, much of the existing laboratory data does not appear to be relevant to such thermal histories due to the atypical temperature-time exposures. Additional field studies of existing thermal discharges are essential if adequate consideration of the biological response (both physiological and behavioral) is to be used in predicting the ecological impact of proposed thermal discharges into natural surface waters.

2. Long-range, properly designed, detailed, quantitative baseline studies of the structure and dynamics of animal and plant communities and their relationship to increasing domestic and industrial influence should be established and supported. These areas should include those that are presently relatively little affected, those that are being affected at an increasing rate, and those that are already seriously affected.

3. There is enough promise in the various possibilities of beneficial uses of heated water effluents that research and demonstration-level work should be encouraged as adjuncts to energy development. Discharges have been used to provide water flow and favorable temperatures for the culture of molluscs, crustaceans, and fishes such as catfish and pompano. Major fish kills due to low-water temperatures are of regular occurrence in shallow inshore waters of the Gulf of Mexico and many lakes in temperate areas. Heated effluents could be used to save fish that otherwise would be lost from such systems. It is, of course, important that all possible benefits of thermal effluents be included in site selection planning, and projected cost-benefit analysis.

4. Evaluations of the effects of the entrainment and subsequent exposure to condenser cooling systems are specific to individual power plants operating on specific estuarine systems. Studies of macrozooplankton and meroplankton effects appear to be worthy of much of this entrainment research effort.

5. Impingement and post-impingement studies of intake systems are also highly site and plant specific and they should be conducted with sufficient frequency to permit a determination of the relative importance of such effects upon local populations of important species. Research efforts designed to clarify behavioral characteristics of fish in intake systems should be intensified to provide data for the refinement and redesign of both operational and mechanical characteristics of screening devices used at power plant intake systems.

6. Research is also needed relative to the environmental impact of alternative cooling devices, such as cooling towers. The impact of mineral loss through drift upon vegetation and setalic surfaces in sur-

rounding areas has not been evaluated for cooling towers of a size applicable to modern fossil or nuclear-fueled plants. The blowdown of dissolved solids and biocides such as chlorine and heavy metals from such towers must also be evaluated in terms of their impact on receiving waters and their associated biota.

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EFFECTS OF SELECTED POWER PLANT COOLING DISCHARGERS ON REPRESENTATIVE ESTUARINE ENVIRONMENTS

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ABSTRACT

Results of investigations into the effects of power plant cooling water discharges into selected, representative estuaries are presented. These studies performed at mid-Atlantic, mid-Pacific, and Gulf of Mexico locations indicate that, at these stations, the cooling water discharges have not adversely affected the surrounding, estuarine receiving water environment. The conclusion is reached that power plants can be operated on estuaries without adverse effects with the result that each potential or existing estuarine site should be evaluated on a "case-by-case" basis.

INTRODUCTION

Large estuaries around the continental United States are used for the cooling and dissipation of heat resulting from thermal electric generation. It is realized that estuaries generally constitute ecosystems of unique importance where adverse intrusions should not be tolerated. However, actual field studies have failed in most instances to reveal such adverse effects resulting from power plant cooling. As an example, the results of environmental studies conducted at electric generating stations on selected representative estuaries are described in this paper.

The power plants' studies as described herein employ conventional once-through cooling systems with one exception where thermal dilution is also utilized. The information presented herein is summarized from reports on studies conducted by:

1. Pacific Gas and Electric Company—Pittsburg, Contra Costa, and Moss Landing Power Plants, Pacific Coast of California.
2. Virginia Electric and Power Company—Surry Power Station, Surry County, Va.
3. Tampa Electric Company—Big Bend Station, Hillsborough County, Fla.
4. Central Power and Light Company—E.S. Joslin Power Generating Station, Cox Bay, Tex.

PACIFIC GAS AND ELECTRIC COMPANY

Pacific Gas and Electric Company (P G and E) operates three electric generating facilities in estuarine environments. Two plants, Pittsburg Power Plant and Contra Costa Power Plant, are located on the Sacramento-San Joaquin Estuary, the great tidal estuary at the head of the San Francisco Bay. The third station, Moss Landing Power Plant, is located on Elkhorn Slough, a coastal lagoon that drains into Monterey Bay and then into the Pacific Ocean.

Facility and Site Description

Sacramento-San Joaquin Estuary

Pittsburg and Contra Costa power plants are located in similar environments, on the south shore of the Sacramento-San Joaquin estuary. (Contra Costa Power Plant is actually on the San Joaquin River, just above its confluence with the Sacramento River). Typical vegetation types in the area include tidal and impounded salt marsh, and drained land that is used agriculturally. On the northern shore of the estuary is Suisun Marsh, a large and productive area for waterfowl and shorebirds. Several federal and state wildlife refuges are found in the area.

The nutrient-rich waters of this system are well-mixed by the diurnal tidal cycle. Salinity variations are seasonal, with ranges from 4 to 10 parts per thousand (ppt). Regulated freshwater inflows determine these salinity profiles. Ambient water temperatures also vary with the season, ranging from 45–72°F.

This nutrient-rich system supports a diverse aquatic food chain, at the top of which are king salmon and striped bass. These anadromous fishes constitute a major sport fishery. Shad, sturgeon, and catfish also form the basis of a growing sport fishery. These fishes feed largely on opossum shrimp, which in turn is supported by a variety of other planktonic species.

The turbid waters of this system, and other available evidence, lead to the conclusion that primary production is limited by low light penetration. The phytoplankton of the estuary is dominated by diatoms, green algae, and flagellates, with some seasonal variation in species composition of these organisms. Bluegreen algae are rare in this estuary; thus, noxious blooms associated with eutrophication have not been a problem.

ELKHORN SLOUGH

Moss Landing Power Plant takes in water from the oceanic Moss Landing Harbor and discharges into Elkhorn Slough. This body of water has experienced several shoreline changes, beginning as a freshwater lagoon draining the Pajaro River. In the early 20th century, the area was developed as a whaling station and smuggling port. Construction of Moss Landing Harbor in 1946 altered the flow characteristics, so that Elkhorn Slough was left with an outlet to the ocean and became subject to the resultant tidal action.

Elkhorn Slough exhibits characteristics of both a true estuary and a coastal lagoon, depending upon the time of year. During the fall and winter rainy season, runoff from local creeks and land drainage provides the slough with sufficient freshwater to dilute the salt incursion from the ocean. In the summer dry season, however, the creeks dry up and land drainage decreases, so that salinities rise and Elkhorn Slough displays most of the characteristics of a lagoon.

Water quality in Elkhorn Slough is primarily dependent upon tidal action and the dairy and cannery waste discharges that have contaminated the Slough and Moss Landing Harbor for several years. Salinity in the system ranges from approximately 20 to 37 ppt. Ambient temperatures range from 50–61°F.

The marine environment of Elkhorn Slough is characterized by muddy bottoms, with a benthic fauna dominated by venus clams. Crabs, shrimps, and oysters are also found. Stands of eelgrass provide sheltered spawning areas for flatfish, which are a major sport fish in the area. Other important sport fish, such as perch and Pacific herring, spawn in Elkhorn Slough.

POWER PLANT OPERATING CHARACTERISTICS

These three power plants are fossil-fuel fired and employ once-through cooling water systems. Significant characteristics of these facilities are as follows:

Power plant	*Year of initial operation*	*Rated output, MW*	*Cooling water flows, cfs*	*Temperature increase, °F*
Pittsburg				
Units 1–4...	1954	630	900	15.0
Units 5–6...	1960	650	722	18.0
Contra Costa				
Units 1–3...	1951	348	600	16.0
Units 4–5...	1953	232	245	12.0
Units 6–7...	1964	680	681	24.0
Moss Landing				
Units 1–3...	1950	348	629	15.5
Units 4–5...	1952	234	223	24.0
Units 6–7...	1964	1,478	1,354	20.0

Moss Landing's Units 6 and 7 do not affect the estuarine environment, as the cooling water source and discharge sink is the Pacific Ocean.

Results of Studies Performed

P G and E conducted 1-year studies at these and five other coastally-located power plants during 1971–1972. Requirements for these physical and biological studies were set by the Regional Water Quality Control Boards. The general objectives of the studies were to determine the areal distribution of the thermal plume in the physical environment, to investigate the effects of each thermal discharge on the principal levels of the local food chains, and to determine measures of protecting the beneficial uses of the receiving waters.

PHYSICAL STUDIES

Synoptic physical studies were performed to simultaneously measure water-quality characteristics over a wide area at each power plant. Parameters measured included surface water temperature, horizontal and vertical water temperature profiles, salinity and dissolved oxygen at three depths, bathymetry and temperature decay rates. Analysis of these measurements not only delineated the extent

and physical impact of the thermal plume, but also enabled the biological investigators to select appropriate sampling stations and methods.

Physical studies showed that the average extent of the thermal plume (area enclosed by the 4°F isotherm) was 50 acres at Pittsburg and Contra Costa and 230 acres at Moss Landing. No effects were found on salinity and dissolved oxygen concentrations.

Biological Studies

Quantitative biological studies focused on three major groups of organisms: zooplankton, benthic organisms, and fish. Standard methods of collection, such as Ponar grabs for benthic sampling and otter trawls and gillnets for fish sampling, were used wherever possible. Some situations required the development of special equipment. In most studies, organisms were collected in a systematic fashion, usually by transect, and identified as precisely as possible. The data were analyzed to give the total number of individuals present, the total number of species present, and an index of species diversity. These parameters were correlated with physical parameters such as temperature, salinity, depth, and time of year.

The zooplankton studies at Moss Landing Power Plant made a further analysis of mortality to zooplankton passing through the cooling water system. This was done by sampling with a specially-designed filter pump at the intake and discharge, coordinating the sampling with the measured travel time of 10.9 minutes. Live and dead zooplankters were manually counted under a stereomicroscope and percent mortality due to passage through the cooling water system was determined by subtracting intake mortality from discharge mortality.

In general, the biological studies yielded the following results:

1. Zooplankton mortality varies from plant to plant and from species to species, within a range of zero to 15 percent. At Moss Landing, the average net mortality was about 11 percent. That is, 89 out of 100 zooplankters passing through the cooling water system can be expected to survive the expected physical and thermal effects.
2. Benthic species diversity was not significantly correlated with temperature differentials. This result is consistent with the observation that the dominant plant influence, the thermal plume, lies in a buoyant surface layer separated from the benthic organisms by water of ambient temperature.
3. Different fish species showed preferences for different temperature regimes. In the Sacramento-San Joaquin estuary, for example, white catfish were most often found near the power plant discharge areas.

Summary of Effects Upon Receiving Waters

The studies conducted at Pittsburg, Contra Costa, and Moss Landing Power Plants have shown that the major detectable influence upon the environment is the thermal plume. No other physical-chemical parameters have been affected. Biological studies show that the aquatic communities have not been significantly altered. Finally, the power plant operations have had no detrimental effects upon beneficial uses of the receiving waters.

VIRGINIA ELECTRIC AND POWER COMPANY

Facility and Site Description

The Surry Nuclear Power Station of the Virginia Electric and Power Company (Vepco) is located on Gravel Neck in Surry County, Va. adjacent to the tidal James River, a major tributary of Chesapeake Bay. The station consists of two Westinghouse pressurized water reactor units, each capable of generating 822.5 MW. Water is required at a rate of 1871 cubic feet per second (cfs) per unit to handle a heat rejection rate of 11.8×10^9 Btu/hr by once-through cooling. This results in a temperature rise across the station of 14°F.

The cooling water discharge structure, located on the upstream side of the Gravel Neck peninsula, is about five miles from the intakes, and is designed with an exit velocity of 6 feet per second to promote rapid mixing with ambient water in the three-mile-wide James River. Physical model studies at the U.S. Army Corps of Engineers facility at Vicksburg, Miss., were conducted to determine the optimum design of the discharge structure.

The James River in the vicinity of the station is shallow, but has a maintained shipping channel. River widths vary from about three miles at the discharge to about four miles at the intakes. Salinity varies from freshwater to about 15 ppt, being dependent on freshwater inflow from the upstream 9,886-square mile watershed of the James.

Surry Units 1 and 2, which began commercial operation in late 1972 and early 1973, are base-load units that operate at an annual average capacity factor of approximately 80 percent.

Results of Studies Performed

PHYSICAL STUDIES

The James River around Surry has been, and is, the object of a continuing and intensive physical study that began in 1969. As stated previously, the distribution of the summertime thermal plume was predicted through the use of a physical model. Wintertime thermal predictions were made by Pritchard-Carpenter, Inc., using a mathematical model.

Several methods are being used to field-test model predictions. Tower and buoy locations in a 10-mile section of the river encompassing the station have been instrumented to provide continuous temperature data. In addition, monthly boat surveys are conducted to determine surface to bottom profiles.

Since, during the course of a year, salinity in this part of the James is highly variable, monthly boat surveys are also used to determine cross-sectional and longitudinal salinity profiles. These studies will determine if the pumping of 3740 cfs of slightly higher salinity water into an area of lower salinity will alter the natural salinity regime.

Results of the temperature studies indicate that the physical model predictions were conservative; that is, the excess temperature plume mixes rapidly with the river water, and water at a given temperature does not encompass as large an area as had been predicted. Studies have shown that the salinity regimens of the river have not been significantly altered by the present station operation.

Biological studies at Surry have attempted to determine the preoperational "health" of the aquatic ecosystem by examining specific food chain components; and to determine the effects, if any, of Surry Power Station operation on that health. Studies to date, which include both preoperational and post-operational data have shown that operation of the Surry Power Station has had no observable adverse effect on any of the various components of the aquatic community in the James River.

Studies that are site-specific to Surry were begun in early 1969 by Virginia Institute of Marine Studies. These studies encompass almost every level of the food chain and include phytoplankton, zooplankton, bottom organisms (benthos), and fouling organisms. In the spring of 1970, Vepco personnel began a study of the young fishes that inhabit the shallow water zones of the area.

Although many theoretical, but as yet unproved, implications of thermal discharges have received widespread publicity, one parameter of power station operation is of immediate concern. That parameter, fish impingement on intake trash screens, receives adverse publicity when fish numbers become relatively large even though the biological significance might be small.

To alleviate the problem, Vepco invented and installed at Surry a unique intake screen designed specifically to return impinged fish to the water alive. Results of studies to date show that an average of 85 percent of the impinged fish are returned alive to the water; survival of most species approaches 100 percent. This screen represents a significant development in the industry and may prove to be one of the best available technologies in dealing with the impingement of fish at intake structures.

Summary of Effects Upon Receiving Waters

The data developed from comprehensive biological (phytoplankton, zooplankton, benthos, fouling organisms, and finfish), chemical, and physical studies in the tidal segment encompassing the Surry Power Station indicate that operation has not modified any of the measured parameters beyond the limits of natural associated variation. Finfish, the major class of organisms with commercial or recreational importance in this tidal segment, have exhibited consistent diversity, evenness, and richness during the four years of study. This is illustrated by the enclosed figure.

TAMPA ELECTRIC COMPANY

Four years of intensive investigation at Big Bend Station have shown that the operation of the plant has not significantly altered the marine life of Hillsborough Bay. The study began in April 1970, seven months before the startup of the first unit and has continued through the operation of two 375 MW coal-fired units.

Facility and Site Description

Big Bend Station is located on the eastern shore of Hillsborough Bay, an extension of Tampa Bay, in Hillsborough County, Fla. Tampa Bay is located on the west central gulf coast of Florida and is a complex system of bays and estuaries including the Hillsborough River, Manatee River and Alafia River estuaries, and Tampa Bay, Old Tampa Bay, Hillsborough Bay, and McKay Bay.

Hillsborough Bay, a natural arm of Tampa Bay, is approximately eight miles long and four miles wide. Two rivers, the Hillsborough River and the Alafia River, and numerous streams flow into Hills-

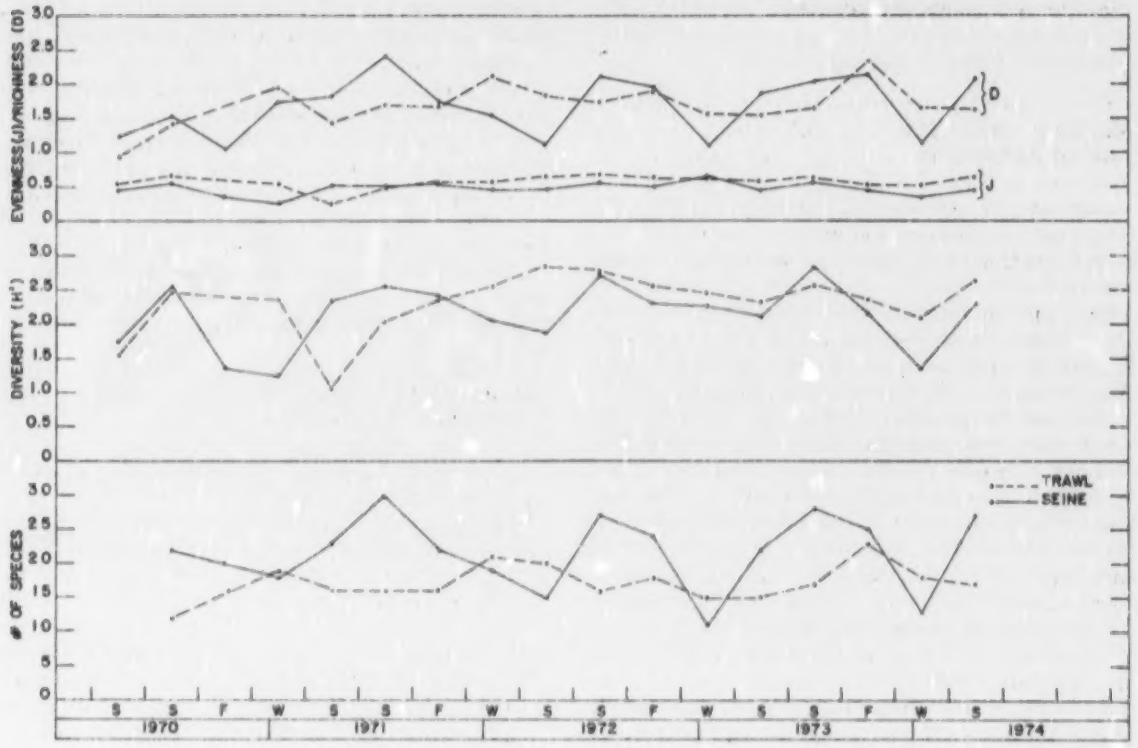

FIGURE 1.—Composite of numbers of species, diversity (H'), evenness (J), and richness (D) by season for seine and trawl samples—Surry Power Station.

borough Bay. The natural shore line is typical of this section of Florida, with coastal mangrove lowlands and pine-palmetto uplands. Much of the natural shore line has been developed and altered by dredge and fill activities.

The maximum natural depth in Hillsborough Bay is 28 feet with improved ship channels maintained at 34 feet. The surface area is 39.6 square miles. The diurnal tide range is 2.8 feet and the mean level is 1.4 feet. The average depth at mean tide is 8.95 feet.

Water quality in Hillsborough Bay is the worst of the bay systems. Effluent from numerous industries and several sewage treatment plants flows into the bay. Monthly temperature averages vary from 61.8–88.4°F over the year. The salinity range is 0.5–30.0 ppt.

High chlorophyll *a* determinations (maximum of 48.76 milligrams per liter) indicate that Hillsborough Bay exists in a high trophic state, carrying a large plant biomass. This is consistent with the high nutrient levels generally found in these waters. Light penetration is sufficiently low to preclude significant stands of rooted algae. Most of the biomass is present as plankton and floating algae.

Benthic organisms present in the bay are mostly filter feeders, which utilize the large amount of plankton present.

Big Bend Station is a coal-fired station consisting of two operating units rated at 375 MW each. One 425 MW unit is under constructon.

Unit No. 1 went into operation in October 1970 with once-through cooling and a maximum temperature increase of 17°F. The cooling water flow rate was 240,000 gallons per minute (gpm). Because of pressure from the Florida Department of Pollution Control, Unit No. 2, which went into operation in April 1973, was constructed with a thermal dilution cooling system. This system consists of a 400,000 gpm pump and associated sheet pile walls to deliver the unheated mixing water to the discharge point of Units 1 and 2. This 1:1 dilution reduces by 50 percent the temperature rise to the bay, so that the maximum temperature increase from both units is now approximately 9°F.

Unit No. 3, which should go into operation in the spring of 1976, will have a closed-loop spray cooling system for control of thermal effluent.

Results of Biological Studies Performed

Beginning in April 1970, regular sampling was done near the Big Bend Station to determine the effects of operation on the bay. Trawls, seines, traps, plankton nets, bottom dredges, sample bottles, et cetera, were employed to gather the necessary data. The program began with two full-time scientists conducting the study and peaked last year with six full-time biologists and several other part-time people working on the project. Seven months of preoperational data were gathered, and data collection has continued through the startup and operation of two units. The area around the plant was divided into four ecosystems with 20 sampling stations. The stations were visited at least monthly; many were sampled weekly and some daily. The samples were collected, analyzed in the TECO Marine Research Laboratory, and the data reported to Tampa Electric Company in four quarterly reports and one annual report per year.

The water around Big Bend Station was analyzed for the following parameters: temperature, salinity, transparency, depth, dissolved oxygen, pH, carbon dioxide, phosphate, hydrogen sulfide, trace metals, and pesticides.

Studies to date indicate there is little difference between the intake water and the discharge water with the exception of temperature, which can be attributed to the operation of the power plant.

The following biological parameters were studied in the vicinity of Big Bend Station: fish, plankton, benthic organisms, algae, invertebrates, chlorophyll *a*, and miscellaneous observations.

Collections of fish from the Big Bend study were compared with a 22-month study of the fish of Tampa Bay conducted during 1957–1959 by the Florida Department of Natural Resources (DNR).

At Big Bend a total of 86 species of fish were caught in a relatively small area near the plant, compared to 73 species caught by DNR in all of Tampa Bay. The Department of Natural Resources collected 11 species not collected by the Big Bend Lab. The Big Bend Lab collected 24 species not found by the DNR study. It would, therefore, appear that the area around Big Bend Station contains a fish species diversity indicative of a low stress condition.

More than 150 species of phytoplankton have been found in the vicinity of the plant. There seemed to be little significant difference between the number of species and individuals in the intake water and the discharge water. The biggest variations in numbers occurred during plankton blooms, and were not associated with plant operation.

Over 70 species of zooplankton have been identified during the study. These represent a normal, balanced community typical of waters of this type.

Benthic populations in the vicinity of the plant and other portions of the bay are sparse, primarily because of the poor substrate in the area. Years of improper dredge and fill operations and other activities have left a layer of soft, silty mud over much of the bottom.

As mentioned previously, turbidity of the water precludes significant stands of rooted algae and the most abundant species of algae found in the area are *Gracilaria* and *Ulva*. Both of these occur in nuisance proportions and are indicative of the nutrient-rich bay waters.

Differences in chlorophyll *a* readings at the intake and discharge were slight. The biggest variation occurred during plankton blooms that were not associated with plant operation.

After evaluating all of the data gathered in four years of study at Big Bend Station, the staff concluded that the operation of Big Bend Station has not significantly altered the marine life in the vicinity of the plant.

Summary of Effects Upon Receiving Waters

Studies completed to date show that little change attributable to power plant operation has occurred. Although temperatures have increased in the receiving waters, other physical and chemical effects are undetectable. The biological studies have shown that phytoplankton, zooplankton, and fish populations near the plant have similar, if not greater diversity and richness than that found in all of Tampa Bay. The benthic community is sparse, but this is probably unrelated to plant operations.

CENTRAL POWER AND LIGHT COMPANY

The E. S. Joslin steam electric power generating station is owned and operated by Central Power and Light Company and is located near Point Comfort, Tex., on a small, tertiary estuary called Cox Bay. Cox Bay is part of a larger estuarine system known as the Matagorda Bay System located in central south Texas.

Facility and Site Description

Cox Bay, the receiving bay for Joslin Power Station, is similar to most Texas estuaries. It has an area of approximately 6,000 acres with an average depth of five feet or less. It generally varies from an oligohaline (brackish water) to a mesohaline (medium salinity) bay. It serves as a nursery area for many marine organisms and is valuable as a shrimp nursery area, particularly for white shrimp.

Texas estuaries are among the most productive of the estuarine systems. A number of characteristics separate them from many of the classic examples referenced in the literature. Among these characteristics are: 1) Lunar tidal influences are slight (less than 1 foot), and as a result, tidal variations are more susceptible to wind velocity and direction. 2) Texas estuaries are generally very shallow and often vertically mixed rather than stratified (exceptions being deep areas in channels). For this reason, these areas are subject to wide temperature ranges. Sudden temperature variations may occur within a short period of time, resulting in fish kills due to cold weather. 3) In many areas, primary productivity is from the watersheds of the coastal streams or by marine grass flats rather from phytoplankton. 4) Salinities vary widely from low saline systems along the northern coast to high saline systems in the south. Salinity characteristics of these systems are governed primarily by freshwater runoff via coastal streams, which also regulates to some extent the abundance and types of organisms present in each system.

As in the case of most coastal systems, Texas estuaries serve as important nursery areas for many marine organisms. Most of the organisms present in these bays are migratory, and spawning occurs offshore in the Gulf of Mexico. Postlarvae and juveniles migrate into the bays to grow up. This immigration movement is timed so that peaks occur in spring and autumn, corresponding to peak annual precipitation patterns. These two peaks coincide because most nutrients and organic materials are available in the estuaries following heavy freshwater runoff, so that "dinner is on the table" when the young organisms arrive. Thus, Texas estuaries are very dynamic systems, varying continuously on a daily, annual, and seasonal basis.

Power Plant Operating Characteristics

Joslin Power Station has a generating capacity of 240 MW and utilizes once-through cooling. Cooling water is taken from the Matagorda ship channel and discharged into the northern portion of Cox Bay. Pumping rate of the power plant is approximately 150,000 gpm with a maximum 15°F increase across cooling condensers. Two additional waste stream discharges enter into the cooling water prior to its discharge into the bay. These are the waste material from a secondary sewage treatment plant located on the power plant property, and a demineralizer waste discharge that has been treated for neutralization.

Originally, the power plant was equipped with amertap as a cleaning device for cooling condensers. However, after one year's operation, the system was found to be inefficient for keeping condenser tubes cleaned, and chlorination was added to the treatment facilities. Chlorination generally occurs two hours a day, five days a week, with a discharge residual of 1 part per million.

The power plant began operation in June 1971 and has continued to operate until the present time. Two years prior to power plant operation, an environmental study was initiated on the Cox Bay estuary. That study has continued to the present time. Therefore, data are available to evaluate the bay prior to the operation of the power plant and to determine its effects upon the receiving waters.

Results of Studies Performed

Biological samples were collected monthly at 21 stations, beginning in August 1969, and continuing to the present. Samples consisted of phytoplankton, zooplankton, benthos (bottom-dwelling organisms such as clams and worms), and nekton (free-swimming fish and large invertebrates). In addition to these biological samples, chemical samples such as dissolved oxygen, salinity, temperature, and pH were taken at all biological stations. Additionally, plume analyses were made by plant personnel and occasionally by biological sampling crew. Results of these studies have been written up in a report entitled, "Final Report. Ecology of Cox Bay, Texas, 1969–73." Results shown here are excerpts from the Final Report.

Typical summer plumes vary considerably depending upon several factors. One is the electrical load of the power plant at the particular time the data were taken. Since the intake pumps at a constant rate, temperature at the discharge varies with the load on the plant at any given time. Maximal temperature increase above ambient varied from 6 to 13°F at the discharge. The shape and extent of the plume is also dependent upon wind speed and

direction. Prevailing winds in the area are from the southeast and tend to keep the plume pushed against the northwestern shore. However, in wintertime when northern winds are common, the plume may extend over a larger area of the bay surface.

Another way of looking at temperature effects is to determine the average temperature rise at the discharge, and to determine the temperature die-off and distance away from the discharge. In 1971–72, when average temperature increase was slightly less than 12°F, a sharp temperature decline occurred about 1,000 to 1,500 feet away from the discharge. Temperatures were then steady for some distance out to about 3,000 feet away from the discharge. It should be noted that the discharge area in the northern portion of Cox Bay is extremely shallow, with depths of less than five feet along the shoreline. Thus, plume size may be larger than would be expected in deeper water bodies, especially where bottom discharges are feasible.

Circulation changes resulting from power plant operations were minimal. Prevailing winds are from the southeast, and currents in the bay are for the most part wind-driven. Little change could be seen from power plant operation except, of course, the flow of water southward from the north shore in the vicinity of the discharge with some eddying effect in that area. Circulation patterns over the rest of the bay remained the same. No recirculation of heated water was determined during the course of the study.

Diversity indices were calculated for all groups sampled, i.e., phytoplankton, zooplankton, benthos, and nekton. In all cases, no significant changes in diversity patterns were observed after the power plant went into operation. This is true of both the discharge area as well as the unaffected areas of the bay. In fact, during the two years of power plant operation, nekton diversity indices remained higher in the outfall area than anticipated. Diversity indices were generally highest in Cox Bay at the discharge area, both before and after power plant operation began. Since diversity indices, not only of nekton but all other trophic levels, were relatively unchanged resulting from power plant operations, it appears that the overall health of the community has not been significantly affected by the operation of the power plant.

Another way of examining the effects of the power plant is to look at spatial distributions in Cox Bay related to seasonal occurrence. As stated earlier, Texas estuaries are highly transient systems with migrations of organisms occurring in and out of the bays almost continuously. Seasonal distribution data for total nekton biomass (total weight of free-swimming organisms) indicate that no significant change occurred after the power plant went into operation. These data, coupled with no significant changes, indicate clearly that there is no significant impact on the bay resulting from power plant operation.

It should be noted, however, that there are variations from season to season and from year to year. These are deemed natural fluctuations and are influenced little, if at all, by power plant operations.

White shrimp exhibit some avoidance of the immediate area of power plant discharge, especially during summer months. Since these data were collected, additional studies have indicated that white shrimp generally avoid the hottest portion of the discharge. However, at certain times, especially during early fall and late summer, the white shrimp tend to congregate in the general mixing zone area where temperatures are generally 3 to 4°F above ambient.

Patterns similar to white shrimp distribution have been indicated for other organisms. It generally appears that most organisms avoid the immediate vicinity of the discharge during extreme summer conditions. However, these same areas are often used even more heavily during spring, winter, and fall. Thus, considering the overall annual utilization of the area, there appears to be little, if any, total loss of habitat. As in the case of nektonic organisms, phytoplankton, zooplankton, and benthic samples seem to follow the same general distributional patterns.

Summary of Effects on Receiving Waters

Study results indicate that the thermal plume generated by the E. S. Joslin Power Station is relatively small, with rapid temperature die-off occurring within approximately 1,200 feet of the discharge under normal wind conditions. It appears that species diversity indices at various trophic levels remained relatively unchanged after the power plant went into operation, and that the overall health of the community is not endangered. Additionally, seasonal and spatial distributions indicated that, with some minor exceptions, minimal distributional change had occurred. Thus, it appears that little environmental degradation has occurred as a result of the operation of the power plant.

CONCLUSION

Examples have been selected to demonstrate that power plants can be sited and operated on estuaries

without adverse effects on the receiving water environment. However, since it is recognized that there are instances where adverse effects have been found due to a variety of site dependent reasons, any conclusions as to the effects of power plants on estuarine environments must be drawn for site specific factors as supported by actual field data.

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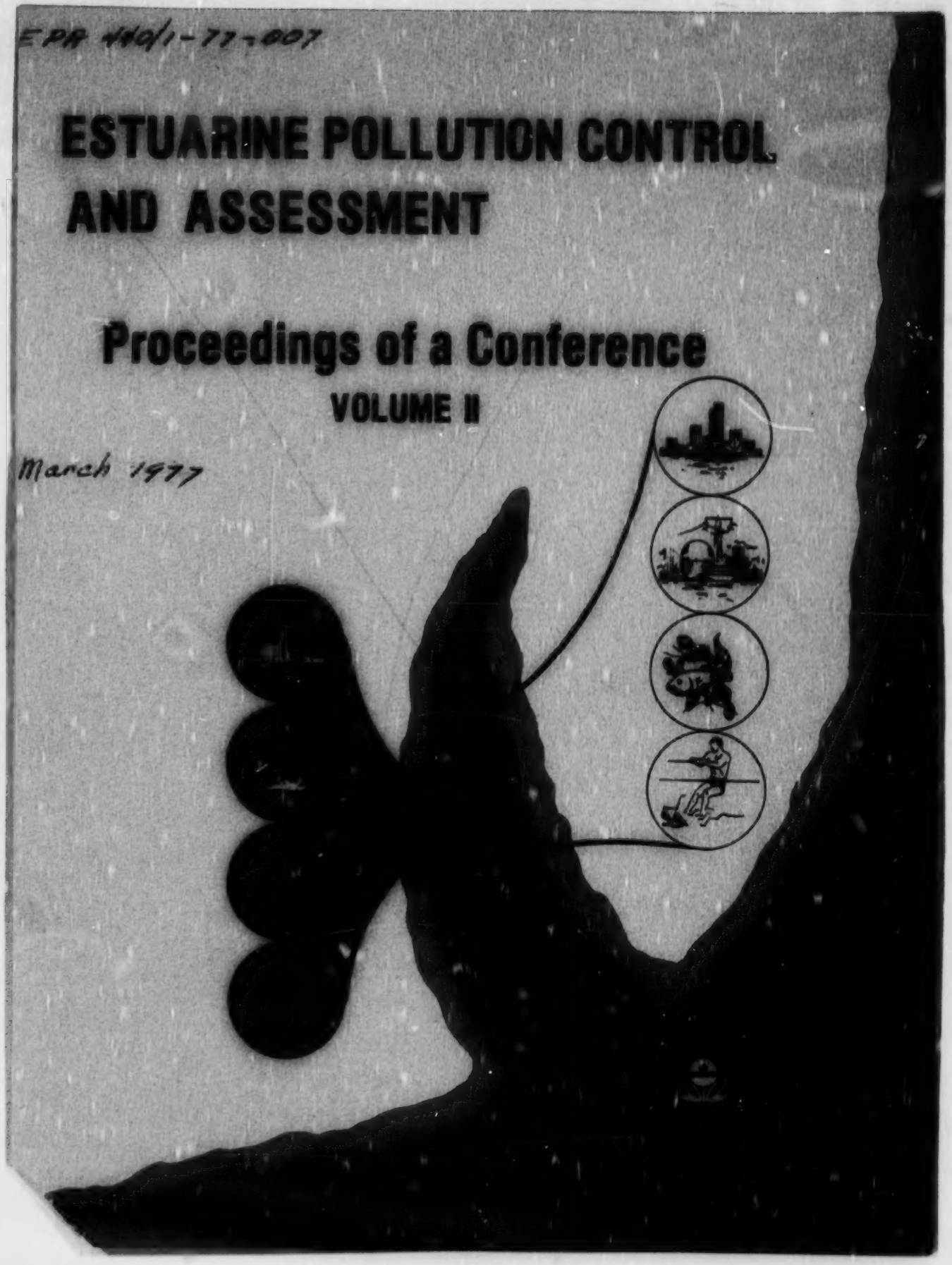
EPA 440/1-77-007

ESTUARINE POLLUTION CONTROL AND ASSESSMENT

Proceedings of a Conference

VOLUME II

March 1977



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OTHER POLLUTANTS

OIL POLLUTION IN THE COASTAL ENVIRONMENT

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ABSTRACT

Petroleum and petroleum products such as fuel oil and lubricating oil are very complex mixtures of chemicals with individual compounds numbering at least in the tens of thousands. This very complex chemical mixture is introduced into the already complex system of interacting physical, chemical, biological, and geological components which constitute the marine environment. Thus, the investigation of the impact of oil pollution on the marine environment is a difficult undertaking which will require much more research before some of the potentially most serious problems are fully understood.

INTRODUCTION

Oil pollution in the estuarine and coastal environment is the subject of many strong political, economic, and environmental arguments. The advent of new and/or expanding refinery operations, port facilities, deepwater oil terminals, offshore drilling and production, pipelines, ocean dumping, and tanker traffic requires an understanding of the impact of accidentally or intentionally discharged oil on the coastal zone environment.

A major portion of our knowledge about oil pollution has been obtained during the past five years. The acquisition of this knowledge was catalyzed by such well publicized incidents as the massive Torrey Canyon oil tanker spill, the Santa Barbara oil well blowouts and smaller but extensively studied spills such as the West Falmouth, Mass., oil spill (Anon., 1971; Smith, 1968; Straughan and Kolpack, 1971; Blumer et al., 1971a).

The findings of many oil spill studies and laboratory and field surveys of oil pollution are subjects of serious debate within the scientific community, and also within the governmental, public, and private sectors of the world. The controversy involving seemingly conflicting reports about the impact of oil pollution resulted in the convening of a study group by the National Academy of Sciences to ascertain the state of our knowledge with respect to the inputs, fates, and effects of oil pollution in the marine environment and to point to areas in need of further research. The study group met in May 1973. The report will be issued late in 1974 or early 1975 after more than a year of debate and revision. It is clear after reading the final drafts of this report and also the background papers (NAS, 1973, 1974) leading to the first draft, that areas of controversy remain. It is also clear from reading these same reports and reviewing current literature that significant progress towards understanding the inputs, fate, and effects of oil in the marine environment has been achieved.

OBJECTIVES

The objectives of this paper are as follows:

1) To provide a summary of available information.
2) To discuss areas of controversy and areas of limited knowledge.
3) To suggest information which can be of use in making management decisions regarding the estuarine and coastal environment.
4) To suggest some approaches towards providing the further information needed to adequately understand and/or monitor oil pollution.

A review and discussion of the engineering aspects of the prevention, control, and abatement of oil pollution will not be attempted. They are subjects better treated by someone more knowledgeable in the field of engineering. Readers interested in these topics will find them discussed in the Proceedings of the Conferences on the Prevention and Control of Oil Pollution (API, 1969, 1971, 1973).

SOURCES OF INFORMATION

There are numerous sources of published information about oil pollution. These sources include newspaper accounts, technical reports, and refereed scien-

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tific journal publications. Generally, the latter is the information source most highly regarded for its accuracy and objectivity. Scientific journal articles are usually rigorously reviewed by the authors' peers prior to acceptance for publication. There are numerous scientific journal articles dealing with oil pollution. There are, however, far more technical reports reporting on oil pollution studies. The preponderance of technical reports is the result of the need to get information to decision makers, including the public, as rapidly as possible. If a scientist waited for the normal review and publication process in a scientific journal he would experience a delay of approximately 6 to 18 months after writing a report of the study. The demands for information often require a more rapid transfer process from the arena of science to that of decision makers. But a penalty is paid. The peer review process is circumvented unless the decision makers arrange for peer review of the report. They are well advised to do so, including peer review of this report.

It is fortunate that, as previously mentioned, the subject of oil pollution in the marine environment has recently been reviewed by the National Academy of Sciences study group. Readers interested in a detailed review of the subject are referred to the Background Papers for this study and the Final Report (NAS, 1973, 1974). There are also several other reports from workshops, symposiums, or conferences, and books which provide a broad review of the literature or contain in one collection several papers on recent progress (API, 1969, 1971, 1973; Duce and Parker, 1974; Goldberg, 1972 a, b, c; Ketchum, 1972; SCEP, 1970; Smith, 1974; NAS, 1971; Mathews et al., 1971; Hoult, 1969; Boesch, et al., 1974).

Two large collections of references dealing with oil pollution studies are those of the Oil Spill Information Center, University Library, the University of California, Santa Barbara; and the Plymouth Laboratory of the Marine Biological Association of the United Kingdom. I have avoided listing an extensive bibliography because there are over 2,000 references dealing with the various aspects of oil pollution contained in the files of the two bibliographic collections, books, reports, and papers cited above. Rather key references or references to reviews are given.

SOURCES OF OIL INPUT TO THE UNITED STATES COASTAL ZONE

There are several sources for oil entering the marine environment. These are given in Tables 1 and 2 along with the estimated annual input rate for each source. Figure 1 provides a graphical presentation of the pathways of oil input to the marine environment. Table 1 compares the estimates for the world input and those for the United States inputs. Table 2 presents the United States input in

Table 1.—Estimate of petroleum and petroleum hydrocarbon inputs to the marine environment

(Millions of metric tons per year)

	World	U.S.
Normal Operations		
Offshore Production [a]	0.02	0.003
Transportation [a]		
Load on top tankers	0.31	0.05
Non-load on top tankers	0.77	0.12
Dry docking	0.25	0.039
Terminal operations	0.003	0.0004
Bilges bunkering	0.5	0.078
Coastal Refineries [a]	0.2	0.03
Coastal Municipal Wastes [a]	0.3	0.10
Coastal Non-Refinery Industrial Wastes [a]	0.3	0.10
Urban Runoff [b]	0.3	0.10
River Runoff [b]	1.6	0.53
Atmosphere [c]	0.6	0.18
Natural Seeps [b]	0.6	0.12
Accidents [a]		
Offshore production	0.06	0.01
Tankers	0.2	0.03
Non-tankers	0.10	0.02
	6.113	1.510

[a] Estimate with high confidence rating.
[b] Estimate with modest confidence rating.
[c] Estimate with low confidence rating.

Table 2.—United States petroleum and petroleum hydrocarbon inputs to the marine environment

	Million Metric Tons per Year	% of Total
Offshore Production		
Normal operations	0.003	0.20
Accidents	0.01	0.66
Subtotal	0.013	0.86
Tankers		
Normal operations	0.209	13.84
Accidents	0.03	1.99
Subtotal	0.239	14.73
Non-Tankers		
Bilges bunkering	0.078	5.17
Accidents	0.02	1.32
Subtotal	0.098	6.49
Coastal Refineries	0.03	1.99
Coastal Municipal Wastes	0.10	6.62
Coastal Non-Refinery Industrial Waste	0.10	6.62
Urban Runoff	0.10	6.62
River Runoff	0.53	35.10
Atmosphere	0.18	11.92
Natural Seeps	0.12	7.95
Subtotal	0.10	
Total	1.51	

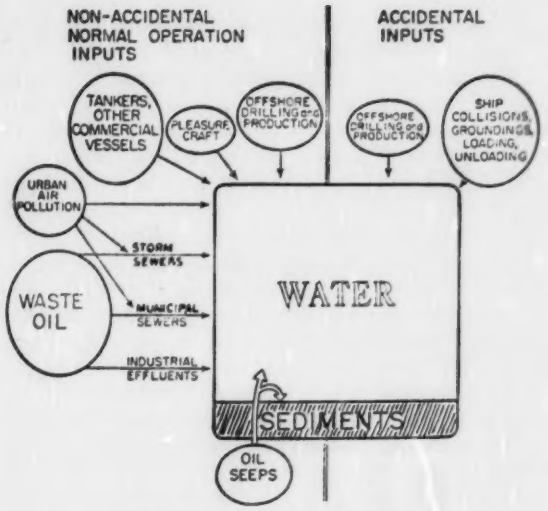

FIGURE 1.—Pathways of oil input.

terms of annual input rates and the percentage of the total input in each category.

Several important points about these tables are:

1) The world input values and some of the United States input values were taken directly from the NAS (National Academy of Sciences) report (1973, 1974). Other values for the United States input were calculated from values given in the NAS report.

2) The estimated input rates are in some cases approximations with a wide range of uncertainty. The NAS report ranked the estimates according to the degree of confidence in the value given. These rankings are given in Table 1.

3) These estimates are global or national averages. The relative importance of the various sources of oil entering the marine environment varies with geographical location and time. For example, a large well blowout would be a massive input of oil to a given location and even when averaged over a 10 year period of time would result in the offshore drilling and production accidental input category dominating inputs for that geographical location.

4) The largest inputs of oil are from normal operations and are intentional discharges. Accidents account for only 4 percent of the U.S. input and 6 percent of the world input to the marine environment.

5) Oil tanker operations account for 16 times as much oil input as offshore production for the U.S., and 20 times as much for world inputs.

When considering the oil inputs to the coastal zone, as opposed to the total marine environment, some consideration must be given to the location of the inputs from tanker operations. The largest input in tanker operations is from ballasting operations. These normally should occur at sea well away from coastal areas. How much of this input actually reaches the coastal areas is a complex function of the physical, chemical, and biological weathering and degradation of the oil and also the surface current system off the coast. My guesstimate is that very little of the total tanker discharge reaches the U.S. coast although the portion that does in the form of tar particles, tarballs, or slicks may be aesthetically unpleasing and contribute to the total impact of oil pollution on the ecological integrity of the coastal zone.

6) The atmospheric input figure given in Table 2 is the estimated U.S. input to the world oceans. The input to the coastal zone from dry fallout and rain is some unknown fraction of the value in Table 2.

7) The input from rivers and from land operations contiguous with the U.S. coastal waters is substantial and accounts for 57 percent of the total input.

8) The effect of the input from the various sources can be quite different. For example, accidental spills are point source and point in time inputs which may have immediate acute effects and long term chronic effects. Municipal or industrial effluents on the other hand may have no measurable immediate impact but may have long term chronic effects as the concentration of the petroleum chemicals builds up in the ecosystem receiving the input.

Management Decisions Suggested by the Input Data

Several important points relating to the control of oil pollution discharges are suggested by our current knowledge of oil inputs to the coastal zone.

1) The largest category of inputs is the chronic dribbling of oil into the coastal zone by industrial and municipal effluents, urban runoff, and river runoff from inland areas. Thus a substantial amount of oil will be discharged to the U.S. coastal zone regardless of whether it is transported to the coastal zone via tanker or produced by offshore wells in the U.S. coastal and continental shelf waters. Unless steps are taken to reduce it this input will increase as our oil consumption increases.

Management decisions which would have a significant effect in reducing this input are:

a. Reduce per capita oil consumption.
b. Encourage re-refining or reuse of waste oils. This would reduce inputs and help conserve a valuable natural resource.

c. Require the application and/or development of technology to reduce the amount of oil in industrial effluents, including refinery effluents. This applies both to effluents discharging directly to streams, rivers, or coastal waters and those discharging to municipal sewers.

2) Drilling and producing oil in offshore areas is safer for the total marine environment than importing equal quantities of oil because current estimates are that approximately 0.014 percent of oil produced offshore is discharged to the marine environment, whereas about 8 times as much or 0.11 percent of the oil transported by tanker is discharged to the marine environment. This assumes that oil produced offshore from a given location is piped ashore and refined or used there without subsequent transportation by sea to other locations. The statement must also be qualified in that it is assumed that the impact of accidental spills and chronic small inputs from oil tankers and from offshore production and drilling have similar effects per unit amount of oil input. Finally, this statement does not take into account the ecological damage which may result in coastal areas due to the construction and maintenance of pipelines and onshore facilities.

IDENTIFICATION OF SOURCES OF MYSTERY OIL SPILLS

Mystery oil spills for which the source is unknown account for 30 percent of the oil spills in United States waters (NAS, 1973, 1974). There are two potential means by which the source of mystery oil spills can be identified. The first method is active tagging of oil tanker cargoes, pipeline loads, and storage tank contents with microscopic spheres or special chemicals. The size of the bureaucracy necessary to ensure accurate records renders this method impractical.

The second method involves detailed chemical analysis of the spilled oils and potential sources. The chemical parameters are then compared and the best match of a potential source with the spilled oil is attempted. This technique is called "passive tagging" and makes use of the unique chemical composition of each oil to distinguish oils one from another and match oils from source and spill samples. The technique is also referred to as "fingerprinting," which is perhaps unfortunate. Many nonscientists in the field of oil pollution control have mistakenly equated "fingerprinting" in identifying mystery oil spill sources with fingerprinting in criminology. This is not the case. The former is in its infancy as a technique.

The success of passive tagging in actually proving beyond a reasonable doubt the source of a spill depends on having a complete collection of all possible sources. Then the analytical chemist applies increasingly more sophisticated analytical techniques until the parameters of one potential source match the parameters of the spill sample. However, if the actual source is not present in the sample collection incorrect identification could result. It could be that a further application of more sophisticated chemical analysis would have shown that in fact the source was not among the collection of possible sources. Passive tagging can be used to eliminate possible sources and give a probability estimate of the source.

The status of passive tagging in criminal or civil court cases involving oil pollution has yet to be extensively tested. The technique is of use in proving potential sources of a mystery oil spill were not the actual source. The technique used in conjunction with other corroborative evidence may provide sufficient evidence to identify the source of a spill. Aside from the legal aspects, passive tagging may provide some estimate of the extent and severity of oil pollution from a known source such as a refinery effluent, producing well, or accidental spill of known origin.

The scientific and technical aspects as well as limitations of passive tagging are discussed in detail by Zafiriou et al. (1973), Gruenfeld (1973), Lynch and Brown (1973), Miller (1973), and Coakley (1973).

PATHWAYS OF TRANSFER AND FATES OF OIL INPUTS TO THE MARINE ENVIRONMENT

A basic understanding of the various pathways of transfer and fate of oil inputs has been arrived at from laboratory studies, field studies, and the application of existing scientific knowledge of processes in the marine environment. These pathways and fates are diagrammed in Fig. 2. Fundamental questions which are yet to be satisfactorily answered about transfer pathways and fates are:

- What portions of oil inputs follow each of the various pathways of transfer?
- What are the rates of biochemical and chemical degradation of whole oil and components of oil during the various stages of movement through the marine environment?
- What are the final rates of removal of oil by

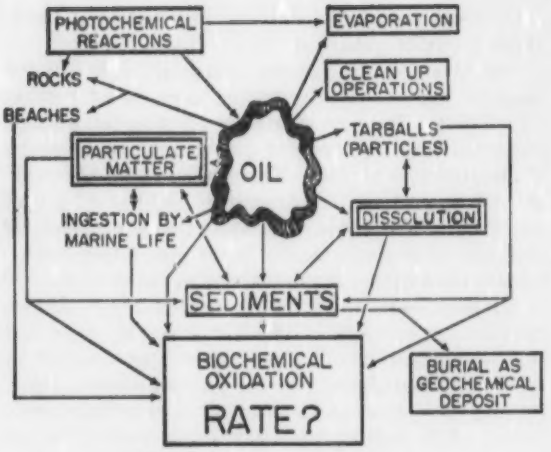

FIGURE 2.—Fate of oil inputs.

biochemical and chemical degradation, and by deep burial in sediments?

Physical-Chemical Processes

Many of the processes which act on the oil result in a fractionation of the oil and selective removal of certain components from the marine environment more rapidly than others. Lower molecular weight components of the type found in kerosene, gasoline, and in varying concentrations of crude oils and fuel oils will evaporate more rapidly than the heavier molecular weight components such as those making up the bulk of lubricating oils. The lower molecular weight components are also more soluble than the heavier molecular weight molecules. For example, several experiments (Boylan and Tripp, 1971; Frankenfeld, 1973; API, 1974) have shown that when No. 2 fuel oil is placed in contact with seawater, the aromatic hydrocarbons of the fuel oil are dissolved or accommodated in the water to a greater extent than are the saturated hydrocarbon components of the oil.

The adsorption of oil onto or into suspended sediments and subsequent washing with water can result in fractionation of the oil with some components adhering more readily to the sediments than others (Meyers, 1972). However, this may not always occur. Mixing of a No. 2 fuel oil with sediment by wave action and turbulence resulted in essentially intact oil being incorporated into sediments (Blumer et al., 1971b).

Once oil is incorporated into sediments it may be transported to other areas by resuspension and transport of the oil polluted sediment (Straughan and Kolpack, 1971; NAS, 1973, 1974; Blumer et al., 1970). Man also plays an important role in this process by dumping oil polluted sediment from harbor dredging and sewage sludge in coastal areas such as the New York Bight (Farrington, 1974). The result of the natural or manmade processes is to spread the oil polluted sediment and thus the affected area increases even though dilution processes may ameliorate the effects somewhat.

Biodegradation of Oil

Extensive research has been aimed towards a better understanding of the biodegradation of oil and individual classes of compounds, and individual compounds found in oil (NAS, 1973, 1975; Davis, 1967; Zobell, 1969; Ahearn and Meyers, 1973). The majority of these studies are laboratory studies. There is little doubt that several species of microorganisms, e.g. bacteria and yeasts, will completely degrade certain components of oil given the right conditions in the laboratory or in the field. It has been established that the rate of degradation will depend on many factors such as the concentrations of nitrate, phosphate, and dissolved oxygen in the water, the presence of other organic compounds, and the history of previous exposure of an area to oil inputs.

Bacteria capable of partially degrading oil have been isolated from several locations in the world's oceans. However, the rate at which the degradation of oil will proceed in the various types of coastal areas is unknown. Also questioned is the potential pathogenicity towards marine organisms for some species of bacteria which might increase in number near or in an oil spill area (NAS, 1974). Likewise, little is known about the toxicity of the chemicals produced by microbial degradation of oil. In fact, we have only rudimentary knowledge of the biochemical pathways and products of the biochemical degradation of oil (NAS, 1973, 1975; Davis, 1967; Zobell, 1969; Ahearn and Meyers, 1973).

Oil in Marine Organisms: Input, Retention, Release, Metabolism

The pathways of oil incorporation into marine organisms are outlined in the left portion of Figure 3. Oil may enter marine organisms by ingestion of contaminated food. Oil may also enter marine organisms from water across membrane surfaces such as gills.

Data collected in three independent studies sug-

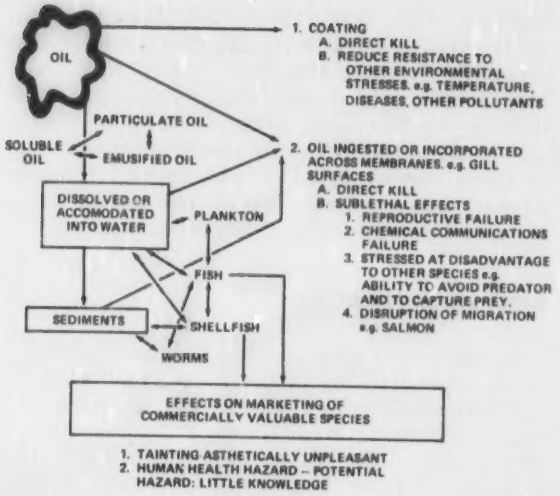
OIL
1. COATING
A. DIRECT KILL
B. REDUCE RESISTANCE TO OTHER ENVIRONMENTAL STRESSES. e.g. TEMPERATURE, DISEASES, OTHER POLLUTANTS
PARTICULATE OIL
SOLUBLE OIL
EMUSIFIED OIL
2. OIL INGESTED OR INCORPORATED ACROSS MEMBRANES. e.g. GILL SURFACES
A. DIRECT KILL
B. SUBLETHAL EFFECTS
1. REPRODUCTIVE FAILURE
2. CHEMICAL COMMUNICATIONS FAILURE
3. STRESSED AT DISADVANTAGE TO OTHER SPECIES e.g. ABILITY TO AVOID PREDATOR AND TO CAPTURE PREY.
4. DISRUPTION OF MIGRATION e.g. SALMON
DISSOLVED OR ACCOMODATED INTO WATER
PLANKTON
FISH
SEDIMENTS
SHELLFISH
WORMS
EFFECTS ON MARKETING OF COMMERCIALLY VALUABLE SPECIES
1. TAINTING ASTHETICALLY UNPLEASANT
2. HUMAN HEALTH HAZARD – POTENTIAL HAZARD: LITTLE KNOWLEDGE

FIGURE 3.—Pathways of oil incorporation into marine life and effects on marine life.

gest that oil incorporation into shellfish and fish is reversible to some extent when the shellfish or fish are placed in clean water for a period of time (Stegeman and Teal, 1973; Lee et al., 1972 a, b; Anderson, 1973). Most, but not all, of the oil taken up from water by the shellfish was discharged within weeks to months. Indications, however, from a limited number of analyses for one experiment reveal that oysters exposed for two months to oil from an oil spill did not appreciably reduce their oil pollutant content even after 180 days in cleaner waters. The fact that this experiment gave somewhat different results than the other experiments may be a result of the heavy dosage of oil experienced by the shellfish under spill conditions.

Fish tested in the laboratory partially metabolized several different aromatic hydrocarbons of the type found in crude and fuel oils (Lee et al., 1972b). Mussels, however, did not metabolize these compounds under similar laboratory test conditions. (Lee et al., 1972a). This points to the obvious danger of extrapolating from one class or species of organism to others. Furthermore, caution should be exercised in extrapolating from the few compounds tested to other compounds in petroleum since differences in the molecular structure of compounds can have profound effects on the rates at which the compounds are metabolized, if they are metabolized at all.

The above studies provided several replicate tests of the uptake of petroleum hydrocarbons from water by marine organisms and the retention and release once these organisms are placed in clean water. Aside from the few measurements mentioned above (Blumer, 1971), there are no studies of the retention of petroleum hydrocarbons taken up under conditions of massive inputs to the organisms' habitat by oil spills. There are also no studies on the uptake, retention, and discharge of petroleum hydrocarbons via ingestion with food. The studies cited above do provide a good model for future studies of longer duration which could test the effects of years of exposure to chronic inputs of oil via uptake across membrane surfaces from water or ingested with food.

An important question for which these studies provide some insight is whether or not there is food web magnification of oil pollutants. An example of food web magnification is the process where oil pollutants of X concentration in phytoplankton would become 10X concentrated in the zooplankton which eat the phytoplankton, and 100X concentrated in the fish which eat the zooplankton. This process would occur if the zooplankton and fish, the higher members of the food web, accumulated all the pollutant they ingested and did not metabolize or discharge a portion of the pollutant. This process, if operative, would mean that many commercially valuable species of marine organisms which are higher members of the food web may concentrate petroleum pollutants to the extent that adverse effects would ensue. There is also the question of whether concentrations would reach a limit which would adversely affect the human consumer. The data collected in these and two other studies (Burns and Teal, 1971, 1973) suggest that food web magnification is not operative for some communities of marine organisms.

Application of Existing Knowledge

BIODEGRADATION OF OIL INPUTS

Investigations of the feasibility of seeding oil spills with bacteria shown to be capable of degrading oil in the laboratory have been initiated (Miget, R. J., 1973). This has been suggested as only a last resort approach by the NAS report (1974). The benefits accrued from releasing an essentially uncontrolled chain of unknown events are far outweighed by the potential hazards at this time.

Applications of existing knowledge about biodegradation of oil may find widespread use in the near future. Biodegradation of oil in industrial effluent holding ponds, tanker ballast waters either in tanks on the ships or in holding facilities on shore may be a feasible method of partially cleaning up this type of input to the marine environment while it is still concentrated at its source (NAS, 1974).

PATHWAYS OF TRANSFER AND FATE

It is known to some degree how oil pollutants move through the marine environment and where they tend to accumulate. This information facilitates surveys of the extent and damage of the oil inputs to the marine environment. It also provides input to models which attempt to predict the movement of oil spills and their severity and extent.

Another application is in the evaluation of the advantages and limitations of methods of treating or cleaning up oil spills. For example, the use of non-toxic emulsifiers (see later section on effects) or dispersants on an oil spill would result in increased dissolution of the oil and accommodation into the water column, adsorption into particulate matter, and incorporation into sediments. On the one hand this might further the biodegradation of the oil by increasing mixing of oil, nutrients, oxygen, and naturally occurring microbial populations capable of degrading the oil. On the other hand, it would spread oil throughout the water column and sediments, potentially increasing the extent and severity of the toxic effects on organisms. The incorporation of significant quantities of the oil into sediments could prolong the exposure of an area to the oil and have an adverse effect on the bottom dwelling organisms. Resuspension of the sediment and transport to other areas would increase the size of the affected area.

The use of sinking agents to remove the slick from surface waters would also result in the incorporation of the oil into sediments and thus may not be advisable for the same reasons cited in the previous paragraph. Of course, in cases where dangers from fire or extensive damage from coating of boats or beaches is the primary concern then the use of sinking or dispersing agents would be advisable.

The discussion in the preceding paragraphs underlines the point that prevention of accidental discharges is preferable to cleanup operations. Likewise, it is clear that research and development concerned with physical contamination and cleanup of oil spills should continue.

Summary

Once oil is released to the marine environment it is subjected to multiple processes and moves via many pathways through the marine environment. Research during the past few years has documented beyond any doubt that the absence of a visible oil slick in no way assures the absence of oil in the underlying waters, sediments, or organisms. Furthermore, oil incorporated into sediments may persist for years (Blumer et al., 1970). Since sediments are an integral component of their environment, this same exposure may affect the adjacent marine environment in varying degrees.

An additional important point to make regarding oil pollution of marine organisms consumed by man is that negative indications of oil pollution by taste panel tests have occurred even when the shellfish tested contained at least 2 ppm (wet weight) of oil pollutants from a No. 2 fuel oil spill as determined by chemical analysis (Blumer et al., 1971b). The chemicals responsible for the adverse taste may be metabolized or released more rapidly than the bulk of the oil pollutants in the organisms. Therefore, negative taste panel tests do not assure the absence of oil pollutants. Furthermore, there has yet to be a study to calibrate taste panel tests with seafood containing known concentrations of oil.

Recommendation

It is essential that further research be conducted on the transfer of oil pollutants into marine organisms, partitioning of the pollutants within the organisms, metabolism within the organisms, and release or discharge of oil pollutants once the organisms are no longer exposed to the oil pollutants in their habitat. This information is basic to understanding the effects of oil pollution on marine organisms, to understanding pathways of transfer and fate of oil pollutants in the marine environment, and to understanding if, when, and how oil pollutants accumulate in seafood.

MEASUREMENT OF AND CURRENT LEVELS OF OIL POLLUTION IN THE UNITED STATES COASTAL ZONE AND CONTINENTAL SHELF

Analysis of Marine Samples to Detect Petroleum Pollution

Discussions of the procedures used and the problems encountered in analyzing marine samples for quantities of oil not visible to the eye are given in several references (NAS, 1973; NAS, 1974; API, 1969, 1971, 1973; Goldberg, 1972b; Goldberg, 1972c). The discussions are of a very technical nature and are best summarized for a report of this type as follows:

1) Several cases have been reported in which petroleum hydrocarbons from accidental spills and from chronic inputs have been detected.

2) No one method of analysis will provide reliable estimates of the concentration of the entire range of

petroleum compounds. Fuel oils and crude oils are complex mixtures of compounds with wide molecular weight ranges. There has yet to be a complete analysis of a single crude oil.

3) There are marked differences between hydrocarbons biosynthesized by organisms and hydrocarbons in petroleum. The latter are very much more complex than the former and include a wide variety of compounds which have not been found in organisms in laboratory culture experiments or in areas where there is little or no petroleum pollution. However, many sources exist for small amounts of hydrocarbons in marine samples: biological processes, geochemical processes, pollution processes. Careful attention to recognizing the possible inputs from these sources is needed in order to detect man's input of petroleum pollutants. In areas where natural oil seeps occur, this problem is extremely difficult.

4) Reports of the presence or absence of petroleum pollution should be carefully evaluated to be certain that the methods of chemical analysis employed would indeed provide the information claimed to have been obtained.

Present Concentrations of Oil Pollutants in U.S. Coastal and Continental Shelf Areas

There are a limited number of measurements of oil pollutants in the water, sediment, and organisms of the United States coastal zone. Only a few locations have been sampled more than once. In addition to the lack of data, it is difficult to compare one area with the other because of the differences in methods of analysis and criteria for distinguishing oil pollutant hydrocarbons from hydrocarbons present due to biogenic or contemporary geochemical processes. Despite these restrictions the data do provide estimates of the present concentrations of oil pollutants and are given in Table 3. These data are taken mainly from the NAS Report with elimination of the data for coastal areas of other countries and for deep sea samples.

General conclusions which can be drawn from these data and the data given in the NAS Report from which they were summarized are as follows.

1) Oil pollutants have been detected in sediment, water, and organisms in areas of large oil spills.

2) Oil pollutants have also been detected in sediment, water, and organisms from areas where no large spills have occurred in the past months or years. These areas are near sources of small spills and chronic dribbling inputs.

3) No more than an estimated 300 analyses for petroleum pollutants in sediment, water, and organism samples have been reported in the literature to date exclusive of reports of visible sheens on the water.

Table 3.—Concentrations of petroleum pollutants in water, sediments, and organisms of the coastal and continental shelf areas of the United States

Water:	less than 2 μg/liter to 50 μg/liter
Sediments:	less than 1 μg/g dry weight to 3500 μg/g dry weight
Organisms:	less than 1 μg/g wet weight to 230 μg/g wet weight
Tar on Beaches:	East Coast (1969)—5 g/meter to 8 g/meter Florida, Miami Beach to West Palm Beach (1973)—avg. of 5.4 g/meter California (1961)—3 to 100 g/meter

NAS (1973, 1974), and references therein.

The fact that there are so few published measurements of the extent and severity of oil pollution in sediments and organisms in United States coastal waters probably testifies to the difficulty of making analytical measurements to detect petroleum pollution. (Goldberg, 1972a).

EFFECTS OF OIL ON THE MARINE ENVIRONMENT

Aesthetic Effects

The coating of beaches, shorelines, and recreational and commercial boats and ships by spilled oil is an obvious adverse effect. This represents a financial loss to boat owners and to the recreational and aesthetic value of a shoreline (NAS, 1974; Butler et al., 1973).

Biological Effects

Toxic Effects

Toxic effects involving the death of the organism exposed to oil may occur soon after exposure to the oil slick or to oil components transported through the water or via sediments as indicated in Figures 2 and 3 and previous discussions. Toxic effects may also occur at later dates as the concentrations of oil in the organisms increase or the oil is transported to new areas.

Toxic effects generally can be divided into two categories: effects from smothering in the oil, or effects from oil taken into the organisms or absorbed into the organisms from water or sediments. Toxic effects have been reported for spilled oil and from studies in the laboratory (NAS, 1974).

SUBLETHAL AND CHRONIC EFFECTS ON ORGANISMS

These effects do not directly result in the immediate death of the organism exposed to oil. There are numerous ways that oil can have an adverse effect on marine life without the result being immediately apparent in the form of dead plants or animals. The types of effects in this category which have been observed or suspected as being important for individual organisms are effects on:

Reproduction
Fertilization and development
Growth
Metabolism—photosynthesis and respiration
Behavior
Cells and organs

Some specific examples of the above are given below. A more detailed presentation is given in the NAS Report (1974).

1) The reduction in the intake and metabolism of phytoplankton detritus by mussels (Gilfillan, 1973)—an effect on metabolism.

2) Reduction in the rates of photosynthesis of phytoplankton cultures (Kauss et al., 1973; Parker, 1974). This is an interference with the process by which carbon dioxide is converted to food for the major part of marine life—an effect on metabolism.

3) Interference with the chemical communication between marine animals. Many marine animals communicate with one another via chemicals given off to the water, i.e. odors. Some predators are attracted to their prey by smell. One study has shown a significant adverse effect on the finding of food by a predator (Jacobson and Boylan, 1973).

Chemical communications or chemotaxis are also important to the reproduction of some animals. Male lobsters are attracted to female lobsters for reproductive purposes by a chemical released by the female. Low concentrations of chemicals resulting from oil in the water may interfere with this process.

A third area where chemical communications is important is in the area of migration to home rivers by anadromous fish for the purpose of spawning. One laboratory study has shown that oil in seawater repels salmon from entering the water of their home stream (Rice, 1973).

The significance of these studies is that they demonstrate the potential effects that low concentrations of oil in water might have if a spill or chronic release occurred at the time of year when marine animals were entering the reproductive phase. The effects on predator-prey interactions would be important throughout the year. These are effects on behavior which result in adverse effects in other functions such as reproduction and metabolism.

4) Blue mussels which were juveniles in the area of the West Falmouth oil spill at the time of the spill developed almost no eggs or sperm the next season (Blumer et al., 1971a). The development of sand dollar eggs has also been shown to be adversely affected by oil in the laboratory studies (Parker, 1974)—effects on reproduction.

5) Effects at the cellular and organ level in clams have been reported. Soft shell clams from an area near an oil spill had a higher incidence of gonadal tumors than soft shell clams from a control area (LaRoche, 1973)—effects on cells and organs and probably on reproduction.

EFFECTS ON THE COMMUNITIES OF MARINE ORGANISMS

Closely related communities of organisms may also be profoundly affected. For example, effects on marsh grasses may cause the marsh to be an unsuitable place for the crabs and mussels which live in the marsh. Effects on worms in the sediments can affect the fish which feed on the worms. Many worms also play an important part in sediment stability. Their tubes contribute to holding the sediment in place. If the worms are killed and the tubes decay the sediment may be easily eroded and the polluted sediment transported to other areas. The movement of the sediment will disturb other organisms living on the bottom even though they might not have been directly affected by the oil.

OIL SPILLS

One of the most heated controversies regarding oil pollution is that surrounding studies of the biological effects of oil inputs to the marine environment. The controversy is due in part to a seeming contradiction of the reported effects or lack of effects when comparing studies of oil spills. The contradiction arises when one does not carefully read reports and take into account two basic sets of factors for oil spill studies.

The first set of factors pertains to the oil spill itself. These factors were set forth by Straughan (1972) and have recently been restated (NAS, 1974). They vary from spill to spill and influence the effect and fate of the spilled oil. They are:

Type of oil spilled
Dose of oil in a given area
Physiography of the area of the spill

Weather conditions at the time of the spill
Biota of the area of the spill
Previous exposure of the area to oil pollution
Exposure to other pollutants
Treatment of spill, e.g. use of emulsifiers, dispersants, or sinking agents

A second set of factors influencing oil spill studies are:

1) A spill is not predictable as to its location and time. In the past, studies of spills have been of the nature of getting out into the area with the best available means at hand and studying what could be studied within the expertise of the scientists involved. In an ideal situation this would involve biologists, chemists, geochemists, geologists, meteorologists, and physical oceanographers. Such a team of scientists is rarely sitting around waiting for an oil spill to happen and as such it is difficult for them to drop everything they are doing and head out for the field or immediately begin laboratory studies.

2) The different methods used to study oil spills, the different animals or plants studied, and differences in the duration of the study vary from one spill to the next. Thus, the task of trying to compare studies from one spill to the next is a frustrating one somewhat akin to comparing measurements of distance in kilometers to measurements of distance in miles without having more than a foggy idea of the conversion factor.

The oil spill studies to date have shown that spilled oil does adversely affect some marine organisms (NAS, 1973, 1974). The effects vary in severity and duration. Complete recovery may take years and is not related to whether or not there are visible concentrations of oil present.

Laboratory Studies of Biological Effects

A comparison of laboratory studies of the effects of oil on marine organisms suffers from many of the same restrictions cited in the above section on oil spills. A variety of oils have been tested on a variety of marine organisms under a variety of laboratory conditions.

However, several studies have been conducted under conditions similar enough or conducted in the same laboratory so that the following comments can be set forth (NAS, 1973, 1974). The studies have shown, as one might expect, that concentrations of oil at which biological effects occur can vary from fuel oil to fuel oil and crude oil to crude oil when tested against one species. The studies have also shown that different species and adults and juveniles of the same species vary in their susceptibility to toxic effects when tested against the same oil.

Effects of Offshore Drilling and Production

The question of the long-term effects of offshore drilling and production on fisheries is one which has no easy answer. Certainly, the fisheries in the Gulf of Mexico have not been destroyed and are a viable sector of the economy. This experience suggests at first glance that no long-term effects have been noticed. However, for the sake of argument I propose the following scenario: Prior to offshore production in the Gulf of Mexico the fisheries there were at a very low level of productivity due to natural causes. During the past 30 years or so the fishery would have increased in productivity potential by a factor of 10. However, because of some unknown and undetected effect of the oil production the fishery only increased in yield by a factor of 2. This factor of 2 suggests by itself that the oil production had no long-term effect and may have been somewhat beneficial. However, we cannot state for certain that there was no effect, since in reality we do not know what the fishery potential would have been without the oil production. The hypothetical factor of 10 which was used for the sake of the argument might have been realized without the presence of the offshore drilling and production activities. Likewise, it may be argued on a hypothetical basis that without the offshore drilling and production rigs the fishery may have declined due to natural causes. Without knowledge of natural fluctuations in fisheries it is impossible to conclude whether or not offshore production adversely affects fisheries.

Several other factors suggest caution when using the Gulf of Mexico fisheries as an example for advocacy of drilling and production in other areas. The oil produced may have a much greater effect per unit weight than the oil produced in the Gulf of Mexico. The fisheries may be of a different type and dependent on species much more susceptible to the effects of oil. The combined effects of oil and a different environment may be more severe.

It is certain that pipelines coming onshore and support facilities on shore can have a severe effect on coastal areas if not properly managed (St. Amant, 1972).

EFFECTS OF REFINERY EFFLUENTS AND OIL DISCHARGED IN EFFLUENTS FROM MUNICIPAL AND STORM SEWERS

Investigations of the effects of oil refinery effluents have shown that release of effluents in sheltered tidal waters killed nearby marsh plants (Baker, 1971). Refinery effluents released to waters exposed to rapid flushing characteristics had little noticeable effect (Baker, 1973). However, only a few segments of the community of marine life were investigated.

No studies of the effects of oil discharged by sewage and storm sewer effluents have been conducted. It would be difficult to unravel the effects of the oil from the effects of the other chemicals in these effluents.

SYNERGISTIC EFFECTS

There is concern that oil pollutants and other pollutants such as PCBs will act in concert such that their combined effects are more severe than predicted from the sum of their effects when acting individually. No reports of such studies have been published to date.

Human Health Considerations

The most significant potential human health hazard is the consumption of seafood contaminated with oil. There are at present no standards for deciding if a particular concentration of oil in seafood represents a human health hazard.

A very emotional controversy centers around the carcinogenic potential of oil contamination of seafood (Anon., 1974). The NAS Report (1974) states—"That the amount of one carcinogen, benzopyrene, entering the oceans from oil is small compared to the amount released into the total global environment from other sources." The report further states "Our knowledge of the properties of all the constituents of petroleum is not complete and therefore there might be some dangerous materials present in petroleum that are still unidentified."

The manner in which the NAS report (1974) approached the problem of carcinogens in seafood could be misleading to the public and decision makers. The report places emphasis on the point that the consumption of oil contaminated seafood by the average consumer would expose the consumer to a very small amount of carcinogens relative to the amount he is exposed to from other sources such as air pollution. I submit that the problem of consumption of carcinogens in oil contaminated seafood should be treated and explained as the problem of radionuclides in seafood is treated and explained. Average inputs or average consumptions should not be used. Rather, care must be taken to ensure that all segments of the population are protected (Bowen, 1974).

An acceptable level for oil in seafood should not be set simply because the average New York resident is exposed to 200 times or more carcinogens from other sources. Rather, the acceptable risk level, if there is one, should take into account the Maine shellfisherman who eats far more shellfish and may be exposed to far less carcinogen input from other sources.

Summary

Documented studies of the effects of oil on marine organisms are limited in number. The data available show that different oils have different degrees of effects on organisms. Effects range from immediate lethality to subtle long-range effects. The effects of a single oil vary from species to species and within a species vary from adult to juvenile.

Our knowledge of the subtle sublethal and chronic effects of oil is severely limited. Data from a few studies provide a basis for concern. Certainly, further studies are warranted based on the data collected on these problems.

It is impossible to decide at present whether or not offshore fisheries suffer long-term adverse effects from offshore drilling and production. The data needed is not available and will be extremely difficult to obtain.

SUMMARY OF MAJOR AREAS OF PROGRESS TO DATE

The last five years have provided significant overall advancement in our knowledge of the input, fate, and effects of oil in coastal and continental shelf areas. There has also been a significant increase in the awareness of oil pollution in the public, governmental, and industry sectors. New laws and regulations have resulted as well as research and development of new technology to reduce oil pollution.

Inputs

Our knowledge of the sources of oil entering the marine environment is now at the stage where we can estimate their relative importance and begin studies to better quantify the inputs. It is known that accidental inputs are a small fraction of the total input even though accidental spills are much

more spectacular. It is known that offshore drilling and production discharges only a small fraction of the total oil input to the marine environment. It is also known that the major input of oil to the marine environment is the result of the chronic dribbling losses which accompany present methods of using oil.

Pathways of Transfer and Fates of Oil Inputs to the Marine Environment

It has been demonstrated once again that the cliche "out of sight, out of mind" should not apply to environmental problems. The disappearance of an oil slick does not mean that the oil has disappeared from the marine environment. Oil inputs move by a variety of pathways through the marine environment and are affected by many processes. The ultimate fates of oil discharged to the marine environment are chemical or biochemical degradation, and/or burial at depth in sediments. Our knowledge is mostly of the qualitative nature of these movements and processes. Extensive quantitative estimates of rates of movement and rates or processes affecting oil inputs are still lacking.

Effects of Oil on the Marine Environment

The known or suspected effects are diagrammed in Fig. 3. The aesthetic effects are obvious. The immediate toxic effects are also apparent from studies of accidental oil spills. Subtle long-range chronic and sublethal effects are known in a few cases and suspected in many others. Effects can be at the level of cells and organs, whole organisms, or communities of organisms.

The chronic long-term effects of offshore drilling and production are largely guessed at or suspected. The long-term environmental hazards or the long-term safety of offshore drilling and production are both unproven.

Human health hazards resulting from eating oil contaminated seafood are suspected but not yet proven.

APPLICATIONS OF OUR PRESENT KNOWLEDGE

1) It appears that the major sources of oil input to the marine environment have been defined. It is clear that the only hope of a significant reduction in the major oil input to the marine environment in the immediate future is a reduction in the total consumption of oil. Since this does not seem likely, programs to reduce the dribbling of oil into the marine environment should be instituted. Reuse or re-refining of waste oils is an example of a program which would help to reduce inputs and conserve a valuable resource.

2) A reduction in ship accidents might be accomplished by better traffic and safety regulations. Reduction in the amount of oil spilled in an accident might be accomplished by the construction of false bottom tankers. The use of the false bottoms as segregated ballast tanks would also reduce the amount of oil entering the marine environment from tanker ballasting operations. A detailed discussion of this subject is given in the Final Environmental Impact Statement, Maritime Administration Tanker Construction Program (NTIS, 1973).

3) Offshore drilling and production with its attendant risks appears to be safer in the long run for the marine environment as a whole than importing an equal quantity of oil. This argument assumes that the oil produced offshore is piped ashore and not transported elsewhere.

If we assume that we will continue to consume oil and even increase consumption, then we should proceed with offshore drilling and production as soon as the problems with coastal land use plans, jurisdiction over offshore operations, and socio-economic problems are resolved.

The arguments about the long-term effects of offshore drilling and production involve such large segments of the marine environment that satisfactory answers will only be obtained by conducting the experiment. That is, conduct the offshore drilling and production in such a manner as to ensure close monitoring and control. Given close monitoring and accompanying research in the laboratory and the field there is a good chance of averting an ecological catastrophe before it occurs. This does not mean that all adverse effects will be detected, but rather that any effects which escape the monitoring and control processes will be small and acceptable in return for the benefit of the oil resource utilization.

It should be emphasized the sacrifice of the long-term potential productivity of the offshore fisheries resource is not advocated. In fact, this would be a primary consideration of any research and monitoring program.

4) The knowledge of pathways of transfer and fate of oil inputs is sufficient to provide an evaluation of some methods of combating oil slicks. In addition, the movement of oil slicks and oil in the marine environment is sufficiently documented to be of some use in making first approximation models of the fate of oil spills (MIT, 1973).

5) We have a fair understanding of the immediate toxic effects of oil. We also have a suspicion and in some cases rudimentary knowledge of the subtle sublethal and long-term chronic effects of oil on marine life. The foundation has been laid for future studies to detail the concentration levels and environmental conditions at which oil will affect marine life.

6) It is known that seafood consumed by man can be contaminated by oil. This should stimulate research to set acceptable levels for human consumption. In this regard, it is essential that the worse possible case be considered for the consumption of oil-contaminated seafood. The experience in protecting seafood consumers from radionuclides should be used as a guide (Bowen, 1974). Use of an average rate of consumption of oil contaminated seafood to arrive at a decision whether there is a serious public health hazard may expose a segment of the population to unwarranted risk.

RESEARCH AND MONITORING NEEDS

Any study of marine environmental quality problems is based on current knowledge of biological, physical, chemical, and geological processes in the marine environment. Continued and increased funding of research towards understanding these basic processes in the marine environment is absolutely essential for short-term and long-term protection and upgrading of marine environmental quality.

Research into general aspects of oil pollution problems or in specific areas should be conducted in a manner which is scientifically sound and flexible enough to pursue interesting and relevant problems as they develop. Available funds should be primarily funneled to scientists via research grants. This mechanism is preferable to the Request for Proposal (RFP) route which seems to be gaining favor in government environmental research management. Research grants written by scientists and reviewed by their peers have a better chance of producing useful scientific information than the RFPs issued in the field of oil pollution research.

More extensive measurement of the extent and severity of oil pollution in United States waters is needed. Measurements should be made in a manner which will provide answers as to pathways of transfer, rates of transfer, processes of transfer, and fates of oil inputs in the marine environment.

Measurements in areas of offshore production, oil ports, and refinery locations as well as control areas remote from these locations are needed to detail man-induced and natural fluctuations. Monitoring should make use of sample archiving as a means of reducing costs. Samples would be collected from several locations within study areas and control areas. However, only samples from key representative locations would be analyzed to determine if adverse effects and/or increased petroleum contamination were present. If such increases or effects were detected, then the entire sample set for that season or year could be removed from archives and analyzed to determine the geographical extent and severity of the effect or increase.

Cost of Oil Pollution Research

The sophisticated types of investigations which are needed to understand the inputs, fates, and effects of oil pollution in the marine environment require substantial funds. For example, the costs for collecting, analyzing and reporting data on the level of petroleum pollutants in samples of water, sediments, and organisms from four sampling sites in an offshore production area and two control areas would be about $180,000 per year if sampling were conducted four times a year. If the costs of biological analyses, geological and physical oceanographic studies are added and the total multiplied by monitoring of three potential offshore drilling and production locations on the Atlantic Continental Shelf, then the cost would be about $2.5 million per year. These estimates are based on current costs of obtaining such data in research programs and may be reduced somewhat by concentration of activities and reduction in cost per analysis because of the large volume of analyses needed.

SPECIFIC RECOMMENDATIONS FOR RESEARCH AND MONITORING

Inputs

1) Reliable identification, quantification, and monitoring of variability of inputs.

2) Development and application of better remote monitoring capabilities.

Measurements

1) Development and/or application of reliable methods for detecting and quantifying oil pollutants in water, sediment, and organisms.

2) Application of these methods in conjunction with investigations of biological effects, transfer processes, and fates of oil inputs.

3) Wider geographical coverage and time series measurements of oil pollutants in the marine environment.

Transfer and Fates of Oil Pollutants

1) Development of models for predicting movement and fate of oil spills and chronic oil inputs. This should be undertaken for harbor areas handling large volumes of oil cargoes, offshore drilling and production areas, oil storage areas, and pipeline routes.

2) Research to better document the rates of biodegradation of oil in situ in the marine environment. This includes research to identify pathways of metabolism or chemical reaction and the effects of the products of these processes.

3) Research to better understand the uptake, retention, metabolism and release of oil pollutants from marine organisms. This includes further research as to whether or not food web magnification of oil pollutants is operative and, if so, when and where.

4) Research to quantify the rates and processes affecting movement of oil through the marine environment.

Effects

1) Toxic effects measurements.

2) Long-term chronic, lethal, and sublethal effects measurements both in the laboratory and in situ.

3) Research on human health aspects of oil pollution of seafood. Needs to be resolved as soon as possible. This is a very emotional issue and one which places federal, regional, state, and local health authorities in a quandry. They have no guidelines to use in deciding when to restrict or allow consumption.

4) All studies of effects should be accompanied by reliable controls and quantitative measurements.

Oil Spill Studies

I have read several final or draft reports of oil spill studies conducted by contractors to the Environmental Protection Agency. Most reports were of limited value. The study teams were environmental divisions of industrial companies or small environmental companies. The teams did not have or obtain the necessary expertise to conduct a very competent study. This could be excused up to two years ago because the areas of study and difficulty associated with the oil spill studies were not widely known to either contracting officers in the Environmental Protection Agency nor to the regional study teams. There is now no excuse for throwing away any more money on studies of the quality of those conducted in the past.

A mechanism for ensuring quality of oil spill studies and at the same time involving competent scientists in oil spill studies is as follows.

Provide funding to a few key laboratories for laboratory and field studies on the effect and fate of new refinery discharges and offshore production. This would ensure that a good solid nucleus of research scientists and associated facilities would be actively engaged in oil pollution research. When an oil spill occurred which, in the judgement of the Environmental Protection Agency project officers and the research scientists, was of interest from the point of view of gaining some knowledge about the fate and effects of oil spills then a study team could be formed by the expansion of the existing research team.

This plan does away with the need for "instantaneous" emergence of a research team at the time an oil spill study is desirable.

Laboratory and Field Studies

The understanding of inputs, transfers, effects, and fates of oil inputs which is needed for effective management of oil inputs and protection of the marine environment will only be obtained by both laboratory and field studies. For example, field measurements will provide an estimate of the existing concentration levels of oil. Laboratory bioassays can then proceed to determine if these have a long-term effect. Conversely, laboratory studies can provide an estimate of the acceptable concentration level of oil in the marine environment. Field studies can establish how close the current concentration levels are to the acceptable concentration level and project when closer control of inputs will be needed in a given area. Furthermore, it is impossible to reconstruct an entire natural ecosystem in a laboratory. Field studies are essential to investigate effects on large segments of ecosystems or entire ecosystems.

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CONSEQUENCES OF OIL POLLUTION IN THE ESTUARINE ENVIRONMENT OF THE GULF OF MEXICO

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ABSTRACT

Incidences of oil pollution have been recorded for over 200 years, but only within the last 10 years has public attention been focused on the problem. Initially, the concern was for the aesthetic and acute effects; but attention has now been largely redirected toward low-level chronic effects, especially those posing a human health hazard. Other areas of increasing concern are the potential synergistic action of oil in conjunction with other pollutants and the long-term chronic effects of oil on the ecosystem. Data available in the literature have served to identify the potential problems, but definition and resolution must await additional data. More emphasis must be placed on translating scientific data into information utilizable for making estuarine management decisions.

INTRODUCTION

The estuaries, unlike true marine or freshwater habitats, continually vary in salinity, and chemical composition and concentration (Christmas, 1973; Odum, et al., 1974). It has been shown that these factors influence the toxicity of oil (Gilfillan, 1973; Tagatz, 1961). Further complicating an assessment of oil pollution on the estuarine ecosystem is the fact that some biological species inhabit the estuary only at certain times of the year (e.g., shrimp), while other permanent inhabitants (e.g., oysters) have different life stages present at different times of the year. Coupling these characteristics with the interaction of other pollutants, the complexity of the problem is clearly illustrated.

While all estuarine areas are under constant threat of damage from oil pollution, particularly in terms of the acute effects caused by major disasters, the estuarine areas of the gulf coast are uniquely susceptible to low-level, long-term, chronic pollution because of the shallowness of the coastal waters and the comparatively small tidal action. Considering the fact that the gulf receives 60 percent of the drainage of the contiguous United States (Geraghty, et al., 1973) and many years are required for recycling the waters of the gulf, the precarious position of the gulf coast estuaries is evident.

Crude oil is not a chemical compound but consists of thousands of chemically identifiable compounds and no two crude oils have the same composition. Fortunately, or unfortunately as the case may be, the addition of an extremely small amount of oil to water will cause a visible sheen. Fortunately, this characteristic alone makes it extremely easy to detect oil, even to an unskilled observer, and it is interesting to note that the Federal Sheen Regulation takes advantage of this characteristic. Unfortunately, there are water-soluble constituents in crude oil, and it has been shown that these compounds can have a deleterious effect on some biological species (Gilfillan, 1973; Nuzzi, 1973; Brocksen and Bailey, 1973; Katz, 1973). Therefore, the lack of a visible sheen does not insure that there is no damage to the ecosystem resulting from oil pollution.

Ever since 1754 there have been reports on oil pollution (Nelson-Smith, 1973). The Torrey Canyon incident in 1967 served to focus worldwide attention on the problem of oil pollution, and there has been an almost overwhelming number of papers on oil pollution since that time. While it has been major oil spills as the Torrey Canyon and Santa Barbara that have been responsible for the intense interest in the impact of oil pollution on the environment, it is ironical to note that these major spills account for only a fractional amount of the oil added to the environment each year. By and large, the huge quantities of oil that find their way into the estuaries of the gulf coast have gone unnoticed by the public. Only recently the public has been aroused to the potential health hazards of low-level oil pollution. For example, a 1973 report (Anonymous, 1973; Hites and Biemann, 1972) on the presence of a variety of organics (including some from oil) in the Charles River must have caused some public concern, particularly in view of the speculation on the possibility of biological magnification of potentially toxic compounds. Even more recently, press releases

have resulted from the EPA report on the New Orleans water supply, linking pollutants contained in drinking water derived from the Mississippi River to cancer (Anonymous, 1974a; Anonymous, 1974b). Mercifully, the articles did not speculate on the potential biological accumulation of these compounds in seafood. This problem will be addressed in more detail later in this report.

The widely circulated article by columnist Jack Anderson emphasized the possible connection between oil pollution and the almost hysterically feared disease, cancer (Anderson, 1974). It is not the purpose of this report to delve into the moral and/or legal aspects of this disclosure (Seltzer, 1974), but merely to illustrate vividly one of the major areas in need of immediate scientific research. In the eyes of many people, the fouling of beaches and the death of large numbers of birds after a major oil spill shrink to insignificance in comparison to the threat of ingesting cancer-causing compounds in seafood or drinking water.

Ecological disaster is ecological disaster, no more, no less. The causative agent is inconsequential in this respect, and pesticides and mercury already have been brought to the public attention. Oil now is being emphasized as the perpetrator of ecological doom. The facts of the case are that the fundamental principles of nature which govern the behavioral, physiological and genetic phenomena are the same irrespective of the toxicant involved. The problem really becomes more one of quantitation and study of the causative agent rather than one of identifying and studying some strange new biological principles. Admittedly, there are some differences in specifics, but by utilizing existing knowledge, the cost and time required to obtain the data necessary for making estuarine management decisions can be significantly reduced.

There are many facets to the problems of oil pollution in the estuarine environment which will not be addressed in this report. The quantities and sources of oil input and its fate in the environment is the subject of another paper for this report. Methods of treating oil wastes, cleanup procedures after accidental spills and the impact of oil drilling and production operations are not considered in this report.

The purpose of this report is to (1) comment on the usefulness of available information on oil pollution from a standpoint of estuarine management; (2) highlight some of the developing areas of concern; and (3) make concrete recommendations concerning future research needs.

VALUE OF CURRENT INFORMATION FOR ESTUARINE MANAGEMENT

From a standpoint of the acute effects of oil, there are numerous reports on laboratory studies and field investigations of accidental spills (Blackman, 1973; Cimberg, et al., 1973; Chan, 1973; Straughan and Abbott, 1970; Holme, 1969; Holmes, 1969; Mackin, 1973; Jones, et al., 1969; Stebbings, 1970; Anonymous, 1956; Spooner, 1969; Straughan, 1969; Burns and Teal, 1971; Valéry, 1968; North, 1967; Mackin and Sparks, 1962; Hay, 1974; Battelle Memorial Institute, 1967; Blumer, et al., 1970). These accounts have documented the fact that crude oils and petroleum products will kill a wide variety of biological species. While these data may be helpful in determining or predicting the extent of damage to a given area, the amounts of oil required to produce acute effects are sufficiently large that they are completely unacceptable from an aesthetic standpoint alone. Obviously then the information is of little value in formulating water quality criteria, effluent standards, and so forth.

The evidence is mounting that even very low levels of oil can cause a myriad of long-range, chronic effects and may even pose a serious human health hazard (Blumer, 1969; Tarzwell, 1970; Nelson-Smith, 1970). This has caused a considerable amount of concern in the public sector.

Laboratory studies are generally carried out under controlled conditions and are useful in identifying and defining potential problems. The data from this type of investigation also are valuable in designing field experiments, but it is hazardous to project laboratory findings into usable information from a decision-making standpoint. In the case of oil pollution, laboratory studies have identified a multiplicity of problems that may occur in the estuaries but have not completely defined these problems.

Data from field investigations on the long-range effects from oil spills are of very limited value for a variety of reasons, including: (1) the lack of adequate ecological baseline data for the area; (2) the impact of cleanup operations; (3) the lack of established control areas required for comparative purposes; (4) the inability to deploy sufficiently large teams of competent experts within the required time frame; and (5) the nonuniformity of methodology and techniques employed by investigators. As a result of these defects, there is an understandable difference of opinion among investigators as to the long-range effects from these oil spills. While differences of opinion are healthy and are to be expected, in some cases existing data are manipulated to prove a given position on the damage caused

by oil pollution rather than objectively interpreting the data as it exists (Mackin, 1973). Surely, many of these seemingly conflicting points of view will be resolved in the foreseeable future.

To date the available data have offered very little information of direct value in making estuarine management decisions, but have identified some of the areas of developing concern. Following is a brief summary of the information available in four of the more important areas of concern.

Potentially Carcinogenic Compounds in Oil

The potential health hazard that could arise from the biological magnification of carcinogenic compounds from oil has been mentioned previously. Highlights from the scientific literature will help to put the problem in better perspective and serve to illustrate some of the complexities involved. In the first place there are reports relating constituents of oil to cancers in a number of fish species (Battelle Memorial Institute, 1967; Tarzwell, 1970). Additionally, there are reports that potentially carcinogenic hydrocarbons are widespread in the marine environment, even in plants and animals taken from areas considerably distant from any known oil pollution (Nelson-Smith, 1973; ZoBell, 1971; Newman and Olson, 1974). This raises the question as to the source of the compounds involved, and it has been pointed out that many carcinogenic hydrocarbons are produced by various species of bacteria, algae and higher plants (ZoBell, 1971; Borneff, et al., 1968). Laboratory studies have demonstrated that microorganisms are capable of degrading these carcinogenic compounds (ZoBell, 1971).

The fundamental principle of preferential utilization of nutrients by bacteria is well established, and it has been shown that this occurs in the case of oil (Phillips, 1972); furthermore, many of the most resistant compounds pose the greatest potential health hazard. Therefore, the basic issue involved is what really happens in the environment. The reports on the persistence of many of these carcinogenic compounds tend to support the view that their biodegradation in nature is a slow process.

Bioaccumulation of many pesticides, particularly the chlorinated hydrocarbons, has received considerable attention by the scientific community. There is reason to believe that the same phenomenon would be observed with components of oil, and, indeed, there are reports to this effect (Nelson-Smith, 1973; ZoBell, 1971).

Differences of opinion exist in the scientific community on the possible links between oil pollution and cancer. There is agreement that considerably more research is needed before a true assessment can be made.

These problems are particularly germane to the gulf coast for reasons cited earlier: the continual input of large volumes of pollutants, the long residence time, and the utilization of seafood resources from this region.

To date, the data available only have served to identify this most important problem, but have not made available the kinds of information required for making estuarine management decisions.

Oil as a Concentrator of Other Toxicants

Potentially, the role of oil as a concentrator of other toxic materials may outweigh its other effects in terms of contributing to the human health problem. For example, one study has shown that the concentration of mercury in oil was 4,000 and 300,000 times greater than it was in sediments and water, respectively, taken from the same area (Walker and Colwell, 1974). Further, increased oil content of sediment samples was associated with increases in zinc, chromium, lead, copper, nickel, cadmium, and mercury (Walker and Colwell, 1974).

The problem of biological magnification of pesticides and its potential significance to the health of the ecosystem and to human health has already been mentioned. In this respect, a recent report on the action of oil slicks as concentrators adds a new dimension to the impact of oil on the ecosystem. Aldrin, dieldrin, DDT, and possibly lindane, heptachlor expoxide, and chlordane were identified from samples taken from surface slicks, but were not in detectable amounts in the seawater samples from the same area (Seba and Corcoran, 1969).

The implications of the concentrating characteristics of oil for both toxic heavy metals and pesticides are obvious.

Effect of Environmental Factors on Oil Pollution

It is a well established fact that the physical, chemical, and biological structure of a system has a significant effect on the action of a given toxicant—oil is no exception. For example, the toxicity of oil increases as the oxygen concentration (Battelle Memorial Institute, 1967; Kontogiannis and Barnett, 1973) or salinity (Rice, 1973) decreases.

The point to be made here is that there is an ur-

gent need to understand the action of oil under different environmental conditions, since the facts indicate clearly that while a given level of oil may be ecologically tolerable under one set of circumstances, it could be disastrous under other conditions.

Long-term Impact of Oil on the Ecosystem

From the literature, a multiplicity of responses to oil would be expected and have, indeed, been reported. Such things as diminishing growth rates in phytoplankton (Mommaerts-Billiet, 1973), physiological stress and degeneration of gill tissue and muscle in oysters (Clark, et al., 1974), changing respiratory rates in salmon and striped bass (Brocksen and Bailey, 1973), and altering behavioral patterns (Rice, 1973; Ecological Research Series, 1973; Boylan and Tripp, 1971) are but a few of the vast array of oil pollution effects.

To gain some concept of the potentially catastrophic effects of oil pollution on the ecosystem, it is necessary only to draw an analogy to the work on pesticides.

1) Gross changes are not required to bring about untimely extinction of a species.

2) A slight lowering of the primary productivity by reducing photosynthetic capability would reduce dramatically the productivity of the entire ocean.

3) Changes in migratory habits, feeding areas, or spawning grounds would jeopardize the current fishing industry.

4) Slight changes in reproduction ritual could upset the balance of the ecosystem.

All biology is geared to survival of the species and is reflected in a buildup of resistance to pollutants or other adverse conditions that may well exact penalties in other species—including man. For example, it has been shown that mosquitofish that have acquired a resistance to insecticides will accumulate these compounds to such high levels that they are fatal to higher members of the food chain (e.g., birds and snakes) (Ferguson, 1967).

RECOMMENDATIONS FOR THE FUTURE

When one considers the fantastic complexities of the estuarine ecosystem with its highly complicated interactions, the literally thousands of compounds present in crude oil, the impact of environmental conditions on the effects of oil on the system, the multiplicity of responses elicited from the presence of oil on the various organisms, and the impact of other pollutants on the whole situation, it would appear that a complete understanding of the impact of oil on the estuarine environment is impossible both scientifically and economically.

The immensity of the overall problem makes it evident that a considerable effort must be put forth in establishing the areas of priority and coordinating individual research. Otherwise, as past experience has demonstrated, there will be a proliferation of small programs resulting in information that is difficult, if not impossible, to use effectively for managing the estuaries. The urgency of the situation cannot be overemphasized.

In terms of priorities, emphasis should be placed on gaining a better understanding of the long-term chronic effects of oil pollution rather than studying the acute effects resulting from major accidents. As indicated earlier, the acute effects are obvious and, by definition, are of a short duration, while the long-term chronic effects may remain for many years and may not manifest themselves until irreparable damage to the area has been done. More specifically, the following problem areas are in urgent need of extensive research, conducted in such a fashion that the data are utilizable for making estuarine management decisions directed toward maintaining our estuaries in a healthy viable state.

Areas of Research

1) *Problems directly related to human health (particularly cancer).* Projects in this category should generate data on the fate of carcinogens from oil in the environment, assess the role of oil in contributing carcinogens to the environment, establish the likely pathways of biological magnification to seafoods for human consumption, establish standards in regard to maximum levels allowable in the environments from which human seafoods are harvested, and establish methods and standards for allowable concentrations of various constituents in seafoods for human consumption. A minor effort also should be put forth to examine ways of reclaiming polluted areas and to develop additional methods of preventing pollution in regard to the carcinogens in oil.

2. *Oil as a concentrator of other toxic pollutants.* With the widespread presence of many kinds of agricultural (pesticides) and industrial (heavy metals) pollutants already present in the environment, knowledge of the interaction of these materials with oil is of vital concern. Numerous laboratory studies have been conducted on the impact of various pollutants on a wide array of biological specimens but,

essentially, no studies have been made on these materials in the presence of oil.

The specific questions to be answered are: (1) Does oil concentrate these other pollutants from the environment, and (2) Does oil enhance the uptake of other pollutants by the biota. The major thrust should be investigations in the field and/or in pilot plant systems as described below. To a lesser degree, some laboratory investigations should be conducted to determine if oil and these other pollutants act independently, synergistically, or antagonistically.

A closer coordination with other research programs could decrease substantially the cost of these studies by a merging of efforts.

3. *Long-term chronic effects of oil on the ecosystem.* The list of problems in this category is rather long and priorities vary considerably from investigator to investigator. Emphasis should be placed on the more long-lasting, potentially disrupting influences that may last for generations, rather than the shorter-term effects for which there is evidence of quick recovery and which are thus concerned primarily with a single generation.

Furthermore, the data should be generated in such a form as to be useful in estuarine management decisions and, as a general rule, should include both laboratory and field experimentation. Some of the more important questions needing attention are: (1) Does oil cause any genetic changes; (2) Does oil alter reproductive processes; (3) Does oil increase susceptibility to disease or increase the virulence and/or numbers of pathogens; and (4) Does oil interfere significantly with vital behavioral characteristics. Of necessity, most of these studies will require multi-year efforts.

It is probable that much valuable information could be obtained by the long-term monitoring of the environment after a catastrophic spill. It is highly important that an immediate post-spill evaluation be made by a coordinated team of competent scientists; this evaluation could serve as a yardstick both for immediate effect and for long-term recovery.

4. *Effect of environmental conditions on oil toxicity.* Because of the constantly changing conditions in the estuary, information concerned with the impact of these various parameters on oil pollution is required in order to manage the estuaries effectively. The effects of salinity and temperatures are but two of the parameters that can change significantly the impact of oil on the ecosystem. The major value of this information is in determining the time and conditions wherein the estuaries are most vulnerable to oil; it will be useful in establishing operational procedures within the estuaries.

Types of Research Efforts Required

To formulate effectively the overall kind of program required to meet the needs, three general types of investigations are needed.

1. *Laboratory investigations.* Many of the problems can be handled effectively by individual researchers working in individual laboratories, but there should be some overall coordination of the specific objectives to be accomplished, though not necessarily the procedures to be employed. In other words, these problems could best be answered by a grant type program, where the emphasis is on the creativity and expertise of the individual scientist. These results will serve as vital inputs to larger programs conducted under more natural conditions. Their value cannot be minimized in terms of their contribution to the effective long-range management of the estuaries.

2. *Pilot plant investigations.* Conceptually, the use of pilot plant systems is routine in the engineering profession. These systems are necessary to test the validity of laboratory findings on a more realistic basis.

For oil pollution studies, the pilot plant could take the form of either an artificially constructed impoundment in the field or a natural area that can be regulated and controlled. Under these circumstances a physically and biologically manageable system with a minimal amount of perturbations from outside forces can be studied. The system would more closely approximate the natural environment and increase the reliability of predictions based on the results of the investigations.

There seems to be little doubt that investigations of this nature have the greatest chance of generating useful estuarine management data in the shortest time frame. These efforts must involve large teams of competent scientists working in a well-planned coordinated program. Unquestionably, large amounts of money will be required, but the cost effectiveness will be an order of magnitude greater than if smaller programs are conducted simply on the basis of multiple use of control data alone. For example, the analyses for oil in the water column and sediments are time-consuming and expensive, and if different investigators are working in different locations or on different organisms, each would require the same analyses.

3. *Investigations of accidental oil spills.* As indicated previously, two of the major reasons for the limited value of the data derived from investigations of accidental oil spills are (a) lack of adequate pre-spill baseline data, and (b) the inability to deploy the

desired scientific staff in time to maximize the value of the data obtained. While this report is directed toward the impact of oil on the estuarine environment, it should be realized that a thorough understanding of the ecosystem is necessary for the most useful management of this valuable resource. This understanding also is of vital importance in determining the impact of pollutants other than oil (e.g., pesticides, thermal pollution, and so on). Economics dictates that only representative areas can be subjected to these kinds of investigations, but years will be required before meaningful data are obtained.

In this connection, it should be pointed out that the institutions of higher learning are an excellent source of expertise and resources for this type of undertaking. While having the scientific guidance of senior scientific personnel, much of the work can be handled by graduate research assistants. In this fashion, not only will the scientific aspects of the program be met economically, but also this plan offers the obvious spin off value of contributing to the badly-needed reservoir of trained environmental scientists for the future. Pursuing this line of reasoning further, there is every reason to believe that many of these same people could become a functional part of the environmental response teams that are needed to investigate accidents. Since the total environmental team already would be in contact and familiar with the ecosystem involved, the problems of an effective response would be minimized. In other words, these university environmental teams will be most valuable to the government and/or industrially contracted response teams in terms of formulating the specifics of the investigation, supplying some of the scientific direction, and making available many kinds of highly specialized equipment and facilities. There is every reason to believe that this kind of interdisciplinary, multi-institutional program can be mounted successfully in an economically practicable and scientifically meaningful fashion.

SUMMARY

If the amount of oil entering the environment each year were reduced to zero, the problems associated with oil pollution would disappear with time. While this may be desirable idealistically, it is certainly unrealistic. More emphasis on preventing accidents, improved technology in containing and cleaning up accidental spills, and an accelerated effort to reduce the input of oil from all sources will reduce significantly the danger from oil pollution. The literature clearly indicates that a substantial effort must be put forth immediately if we are to maintain and/or reclaim our estuaries as a healthy viable resource.

One cannot help but be impressed, in a negative way, by the lack of usefulness of the data on oil pollution in terms of estuarine management. To date, the major value of the research has been in identifying the potential long-range problems that could result from oil pollution of the estuaries. The fact that an ecological catastrophe has not occurred is fortunate and an increased research effort on oil pollution should reduce significantly the probability of such an event. The translation of scientific data into information utilizable for making estuarine management decisions must be accelerated and more emphasis must be placed on determining the costs (both monetary and ecological) as well as the benefits of the various solutions to the oil pollution problems.

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SOLID WASTE DISPOSAL AND ITS RELATIONSHIP TO ESTUARINE POLLUTION

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ABSTRACT

The general relationship of solid waste to estuarine pollution is described. Current major impact of solid waste on estuarine pollution comes from fills, legal and illegal, where leachates contain pollutants including pesticides, heavy metals, and oxygen-demanding materials. Most coastal states have regulated against the further use of estuarine areas for the disposal of solid wastes. It is recommended that the Federal government establish a data bank to determine where the various kinds of waste materials originate and where they are disposed. Long-range solutions to the danger of estuarine pollution by solid waste materials lie in reduction of the quantity of solid wastes generated and in large-scale recycling efforts.

INTRODUCTION

Each year the average person in the United States uses 17,500 pounds of fuel (for warming offices and houses, running automobiles and trains, firing factory boilers, and many other tasks), 23,000 pounds of construction and other non-metallic materials, 6,800 pounds of metallic ores, and almost 6,000 pounds of agricultural materials (Morton, 1974). The annual per capita consumption in the United States, then, is over 50,000 pounds, or nearly 150 pounds per person per day. Since "consumption" really means one-time (usually short-term) use, this quantity of material becomes a per capita solid waste disposal problem. This contrasts rather dramatically with the "tip of the iceberg" of solid wastes visible to most of us who generally think of solid wastes as household garbage and rubbish. But household garbage and rubbish are just one of the 11 major streams of solid waste produced in this country, and account for a minute percentage of the 150 pounds per person per day total waste production.

The 11 major streams of waste may be lumped into the three broad categories of municipal waste, agricultural waste, and industrial waste. Municipal waste includes residential, commercial, and demolition wastes; agricultural waste includes animal manures and waste from fruit and nut crops and from field and row crops; industrial waste includes waste from food processing, manufacturing, and lumbering, as well as chemicals and petroleum.

On a per capita basis, municipal wastes account for about 3 to 5 pounds, agricultural wastes, about 15 pounds, and industrial wastes, nearly 130 pounds per day.

Since nearly 80 million people in the United States live within 50 miles of an ocean coastline, while another 30 million live within 50 miles of the Great Lakes and the St. Lawrence River (U.S. Department of Commerce, 1973), the use of estuarine areas for waste disposal is an important consideration because these have historically been favorite solid waste disposal sites for municipal and industrial wastes. Agricultural wastes have generally been left on fields, burned, or allowed to wash into water courses. Fortunately, as will be shown later, most coastal states have now prohibited the use of estuarine areas for waste disposal. So while filling of estuarine areas is still going on, principally in San Francisco Bay and Hackensack Meadows in New Jersey, no extensive new filling of estuarine areas with solid waste appears to be taking place.

CURRENT DISPOSAL METHODS

The four primary methods of solid waste disposal are, in order of decreasing usage, landfill, resource recovery, incineration, and ocean disposal. Since estuarine areas have in the past been favorite sites for "reclamation" by filling them with solid wastes, this disposal method has had a primary impact on them. Therefore, as resource recovery and incineration become more prevalent, less pressure exists to fill estuaries with garbage. Of course, much solid waste is illegally dumped in estuarine areas.

Landfill is by far the most prevalent method of

disposal in use today, with about 90 percent of municipal waste going there (Feibusch, 1970). Unfortunately, most landfills still do not qualify as "sanitary" landfills as these are defined by the American Society of Civil Engineers (ASCE). A sanitary landfill according to the ASCE is "a method of disposing of refuse on land without creating nuisance or hazards to public health . . . (volume) and to cover it with a layer of dirt at the conclusion of each day's operation . . ."

Properly developed sanitary landfills create useful land for park and recreation facilities. On the other hand, the ecological disruption caused by landfills, particularly in marshland or wetland areas, is a major negative environmental factor.

Significant amounts of waste (particularly industrial wastes) are being reused. The salvage industry today probably does an annual volume in excess of $10 billion. However, most materials now being salvaged are the homogeneous remains of manufacturing processes that are free of contaminants and can therefore be directly reused. Recovery of materials from municipal wastes is currently receiving a great deal of emphasis from planners in the waste management industry. In later sections of this report, we will discuss what efforts the States of Massachusetts and Connecticut are currently making in implementing statewide resource recovery plans.

Probably the major constraints to increased salvage and reclamation efforts are the absence of sustained demand for salvageable material and the incentives to use them. In any case, energy considerations are now forcing all waste management planners to reconsider resource recovery as a major factor in solid waste management.

The best available data indicate that incineration accounts for about 8 percent of the solid waste disposed in the United States. Many communities have recently renewed their interest in incineration in light of the predicted energy shortage. Modern incinerators are said to be 90 percent efficient in terms of residual waste. That is, for each 100 tons of combustible material burned, 10 tons remain to be disposed. Of course, the basic law of physics stating that matter cannot be destroyed is still valid, so the 90 tons of material burned are discharged either into the air or into sewers. The problem of non-combustible materials also remains. Studies in Los Angeles County indicate an overall incinerator efficiency of 48 percent with respect to the average raw refuse composition collected (including bulky materials and non-combustibles).

Less than 10 million tons of solid wastes are disposed of annually into the oceans off the continental United States. In addition, at least 53 million tons of dredging spoils are being dumped into the ocean (Smith, 1971). The question of dredging spoils disposal is currently the subject of a $30 million study by the U.S. Army Corps of Engineers under its national Dredged Material Research Program and will not be further discussed here.

REVIEW OF COASTAL STATES' SOLID WASTE MANAGEMENT EFFORTS

In order to provide an up-to-date review of the status of solid waste management efforts in the individual states, a telephone survey of the 20 coastal states was made between October 30, 1974, and November 11, 1974. In each case, contact was made with a senior official in state government responsible for solid waste regulation and management. Table 1 summarizes information obtained from this survey.

Eighteen of the 20 states surveyed have assumed primary jurisdiction for solid waste management and regulation. Only California and Washington have total local control. Actual situations in Texas and Louisiana reveal effective local control, but South Carolina under present procedures cannot exercise effective state control. Seventeen of the 20 states surveyed have adopted solid waste management legislation since 1970, indicating at least a recognition of state responsibility in the solid waste management field.

Two states, Massachusetts and Connecticut, are proceeding to implement statewide resource recovery plans, while two other states, Delaware and California, are working with demonstrations that may have significant results. Data concerning the location of solid waste fills in estuarine areas were not readily available, although the problem seems confined to the states of Maryland, North Carolina, South Carolina, Florida, Texas, and California. In Louisiana, a state with many estuarine areas, the population in the five parishes where most of the estuaries are located is quite small. It is encouraging to note that only one or two states allow new fills for solid waste in estuarine areas, and that ocean dumping appears to be practiced only in New York and New Jersey.

PROBLEMS OF SOLID WASTE LANDFILLS IN ESTUARINE AREAS

Landfilling of solid wastes in estuarine areas presents a twofold problem. First, it causes a reduction in the limited acreage of marshland and wetland

Table 1.

State	Population (Millions)	Jurisdiction	Date of Enabling Legislation	Status of Resource Recovery Efforts	Number of Existing Fills in Estuarine Areas	New Estuarine Fills Allowed	Ocean Dumping	Acres of Estuarine Area (f) (Thousands)
Maine	1.01	P*	12/73	?	2	No	No	39.4
New Hampshire	.76	P	'72	?	?	No	No	12.4
Massachusetts	5.75	P	4/71	P.I***	1	No	No	207.0
Rhode Island	.96	P	'74	?	1	No	No	94.7
Connecticut	3.07	P	'71	P.I.	?	No	No	31.6
New York	18.35	P	9/73	?	?	No	Yes	376.6
New Jersey	7.31	P	'70	?	1	No	Yes	778.4
Delaware	.56	P	7/73	Demo†	None	No	No	395.5
Maryland	4.01	P	'70	?	15(c)	No	No	1406.1
Virginia	4.72	P	4/71	?	1	No	No	1670.0
North Carolina	5.16	P	'69	?	20	No	?	2206.6
South Carolina	2.63	P(d)	9/71	?	30±	Yes	?	427.9
Georgia	4.66	P	'72	?	None	No	No	170.8
Florida	7.03	P	7/74	?	?	No	?	1051.2
Alabama	3.49	P	'69	?	None	No	?	530.0
Mississippi	2.25	P	'74	?	None	No	No	251.2
Louisiana	3.69	P(a)	?	?	?	?	?	3545.1
Texas	11.43	P(b)	'69	?	Many(e)	No	?	1344.0
California	20.29	L**	1/73	Demo†	31	No	?	522.1
Oregon	2.14	P	5/71	?	1	No	No	57.0
Washington	3.44	L	'72	?	?	No	?	193.8
	111.77							

(a) State must use parish district attorney to prosecute. Since district attorneys are also parish legal advisors, they do not prosecute.
(b) Counties may assume control by adopting solid waste permit system. Only 4 of 254 counties have done so.
(c) Small facilities on Eastern Shore serving total of 20,000 people.
(d) Can be overruled by any professional engineer-prepared plan.
(e) Mostly small sites.
(f) Presented by Dr. Stanley A. Cain, Assistant Secretary of Interior, in testimony to the Subcommittee on Fisheries and Wildlife Conservation.
* Primary state jurisdiction.
** Local control.
*** Statewide plan implementation.
† Demonstration project.

remaining in this country, and secondly, it creates the danger of polluting vast areas outside of the fills themselves through contamination of leachates when water percolates through solid waste. A recent article in Nation's Cities (Weddle, 1974) suggests that dumps, both old and new, may be a potential threat to many groundwater supplies. Certainly if this is the case, estuarine areas in which dumps are located are also affected. Leachate generation in this country, according to the Environmental Protection Agency (EPA), may approach some 46 billion gallons annually. A significant percentage of this leachate enters estuarine areas where it introduces toxicants, heavy metals, and pesticides, and produces oxygen depletion.

The Third National Congress on Waste Technology and Resource Recovery, sponsored jointly by the EPA and the National Solid Waste Management Association, in San Francisco November 14 and 15, 1974, may provide the impetus needed to tackle the problem of leachate contamination on a national level.

SOLUTIONS—LESS WASTE, MORE EFFECTIVE RECOVERY

As suggested in the previous section, much progress has been made in reducing the negative effect of solid waste pollution on estuarine areas. However, ultimately the answers to pollution problems from solid waste of estuarine areas do not lie solely in more rigid regulations or more detailed guidelines. They lie also in producing less waste and in doing a more effective job of recovering fractions of the waste that we do produce.

Management plans for solid waste can no longer be based on least first cost alone. They must be based on the concept of least net cost, taking into account a direct monetary outlay, the cost of environmental pollution, and the value of resources conserved. The "hierarchy of choices" concept for solid waste management is suggested as a systematic approach to solid waste management, minimizing resource waste and maximizing resource recovery. Under the hierarchy of choices, the best waste

management choice is carried to its logical and practical limit, and then the next best choice is applied to what remains. There are six choices, and the waste that is finally left over for burial is a small fraction of the original amount. The hierarchy of choices is as follows:

Source Reduction

This involves modifying some products and materials and stopping the manufacture of others. It would require that serious consideration be given in the design stage to ultimate disposal of any manufactured product. Superfluous packaging materials are obvious candidates for this approach. Action by state and federal legislatures, vigorous support from local agencies, and strong citizen support would be necessary to reduce the production of waste.

Reuse Without Processing

Some glass, metal, and paper articles are suitable for direct reuse. More consideration must be given to encouraging a collection system that separates these materials at the point of origin. The controversial Oregon "bottle law" is an example of state efforts toward reuse of resources.

Reuse With Processing

Materials not suitable for direct reuse, but which can be successfully blended with virgin materials at time of processing (glass, aluminum, paper, tin cans), can be separated at transfer points and made available to industry as raw materials.

Conversion

The organic part of the remaining material can be decomposed into a soil-like humus by composting or pyrolyzed by applying heat in the absence of oxygen. Composted materials would be applied to the land to produce stable topsoil.

Change of State

The combustible material that still remains can be incinerated, producing gas and energy. Incinerators need to be located where there is a demand for steam in the immediate vicinity.

Burial

Some materials will always need to be disposed in landfills. But these landfills should be located where development plans call for changes in existing ground elevations. Since the material that remains after having been processed through the previous five steps in the hierarchy is inert and earthlike, the problem of landfill stability will be greatly reduced.

The hierarchy of choices concept will have to be employed in a flexible way, since local conditions may obviate some and favor others, but if it is employed in a systems engineering sense, it can be appropriate under any given set of circumstances.

ENERGY CONSIDERATIONS

As a nation, we are currently involved in a massive drive to find alternate sources of energy, having recently discovered that a dependence of foreign oil could have devastating effects on our way of life. To a large extent, the whole problem of solid waste management has become affected by the "energy crunch." As with all such crash efforts, it will take several years before we realize that the crucial problem is not how much energy we generate but what our real net energy needs are. Thus it may be that according to the hierarchy of choices concept in the previous section, organic municipal and agricultural wastes can be more useful when converted and added to the land as a soil amendment rather than being burned. Much work needs to be done to minimize the need for energy in solid waste management. The institution of transfer stations where waste materials are transferred from small to large vehicles is one of the more obvious energy-saving devices being considered by many communities.

PROGRAMS WITH PROMISE

As we have mentioned, the States of Connecticut and Massachusetts have taken a leading role in developing statewide solid waste management plans that emphasize resource recovery. The Connecticut plan (Anon., 1974b) proposes 10 regional solid waste recycling centers to be constructed by the Connecticut Resource Recovery Authority (CRRA), a non-profit, tax-exempt public service corporation. Private firms in the resource recovery industry will contract with CRRA to design, construct, and operate the 10 regional centers. Firms have been selected to build plants at Bridgeport and Berlin, Conn. The plants are scheduled to go into operation at the rate of one per year. The first two plants will recover fuel, ferrous metals, aluminum, and glass.

The State of Massachusetts, with a somewhat less ambitious program than that of Connecticut, has approved the development of the first resource recovery facility in Lawrence to serve the regional needs of the Merrimack Valley. This plant is to be built, operated, and owned by private entrepreneurs. Recovery of metals and fuel is envisioned (Anon., 1974a).

The city of St. Louis and Union Electric Company are jointly undertaking a significant program for utilization of refuse for energy production. Shredded air-sorted refuse and coal have been used for some time now on a test basis to generate electricity at the Meramec Power Plant of Union Electric Company in St. Louis. Extensive tests have not revealed any serious problems of air pollution, although modification of the refuse-coal composition and close mixture control were found necessary. Union Electric Company and the city are currently developing a $70 million program for five to seven transfer stations throughout St. Louis, making it possible to use all of that city's combustible solid waste for energy.

The Delaware Reclamation Project proposes to use 500 tons of solid waste and 230 tons of sewage sludge per day and recycle them into marketable materials. This demonstration is essentially to prove the viability of an aerobic digester to produce humus. Other machinery would produce solid fuel, carbon, fuel gas, ferrous and non-ferrous metals, paper, and glass cullet. The plant will be designed with enough capacity to handle all the wastes in Newcastle County (Wilmington).

In the San Francisco Bay Area, a group of 15 local agencies joined together in 1972 to test the feasibility of using composted organic solid waste in the low-lying areas of the Sacramento-San Joaquin Delta for levee stabilization, land building, and agriculture. These local agencies, calling themselves The Bay-Delta Resource Recovery Action Committee, took a first step not only in solving the problem of solid waste (including sewage sludge) in the bay area but also in forming the regional institution framework necessary to do this. This effort was entirely voluntary without coercion from either state or federal agencies.

Briefly, the plan called for strategically located processing transfer stations where directly recoverable materials would be removed. The balance would be shredded and air classified, with the light fraction being mixed with sewage sludge and composted, while the heavy fraction would undergo further recovery processing. The composted fraction would then be shipped by barge to the Sacramento-San Joaquin Delta, where it would be placed behind dikes for support and to raise the land levels, which have been dropping steadily for many years. The composted material would be used to stabilize dikes and to serve as a growing medium for agricultural products. A pilot demonstration lasting three years and using 200 tons of composted material per day has been proposed. To date, the California legislature has appropriated $2.3 million toward the demonstration. The local agencies are currently negotiating with federal representatives for matching funds.

THE FEDERAL ROLE

Current Federal authority in the field of solid waste management as it affects estuarine areas is held by the U.S. Army Corps of Engineers under the Rivers and Harbors Act of 1899. The Corps, under the same act, issues permits for dredging and filling in navigable waters and may deny these permits based on fish, wildlife, and water quality consideration (Anon., 1974c).

The EPA's Solid Waste Management Program has no regulatory authority. Its present role is confined to establishing broad national policies, administering research and development programs, encouraging state and area-wide solid waste management planning, and providing technical assistance.

Many of the concepts proposed in the hierarchy of choices for sound solid waste management and resource recovery are embodied in legislation currently pending before various committees of Congress. The Resource Conservation Energy Recovery Act of 1974 is the most comprehensive bill currently being considered. It addresses freight rate discrimination for recycled products, source reduction efforts, hazardous waste disposal standards, long-range state solid waste management planning, and grant and loan programs for large-scale energy recovery and resource conservation demonstrations as well as full-scale plants.

Committees of the House of Representatives are discussing legislation for tax credits to recycled products manufacturers and rapid amortization proposals for recycling equipment. Both of these pieces of legislation would have a major beneficial effect on reducing the quantity of solid waste that might be destined for estuarine areas.

New legislative proposals are urgently needed that would require the EPA to establish and maintain a data bank of waste materials generated and disposed. No one today has even a general idea as to how much and what kind of material we are throwing away, where it is being thrown, and what damage it is causing. The information gathering effort required to develop this data bank is very

large. However, intelligent long-range planning by both industry and regulators will be impossible until better information is available.

SUMMARY AND CONCLUSION

Each of us in this very affluent country consumes on the average 150 pounds of raw material every day. Since nearly half of us live within 50 miles of coastlines having estuaries, estuaries offer convenient dumping grounds for our leftovers. Fortunately, most coastal states have recognized the ecological importance of estuarine areas and have prohibited their filling with solid waste. So while some filling of estuarine areas is still going on, not many new fills will be started.

Concerns for raw material and energy shortages are likely to have a positive influence on resource recovery and conservation efforts. This will help to reduce the pressure on filling estuaries since less waste will be generated.

Most states have assumed regulatory control over solid waste disposal and appear to have established on-going enforcement programs to prevent estuarine pollution. Massachusetts and Connecticut are embarking on ambitious statewide resource recovery programs, while several demonstration projects with great potential are being initiated elsewhere.

A systems engineering approach is urgently needed to measure the least net cost of solid waste management programs, taking into account cost of pollution prevented and resources conserved. The hierarchy of choices concept is a useful tool in selecting waste management programs. In the hierarchy, source reduction (i.e., not making the product in the first place) is the ideal waste management solution, while throwing it away is the worst.

It is to be hoped that the federal role in the solid waste management field will soon be expanded with the provisions embodied in the proposed Resource Conservation and Energy Recovery Act of 1974 becoming law.

In general, it can be said that much improvement has taken place in the solid waste management field in the past few years, but a great deal more needs to be done before the threat of pollution of estuarine areas from solid waste is eliminated.

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IMPACT OF CHLORINATION PROCESSES ON MARINE ECOSYSTEMS

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ABSTRACT

The use of chlorine as a disinfectant and antifouling agent is reviewed. Chemical reactions of chlorine in aquatic environments are discussed, with particular emphasis on the formation of halogenated organic constituents in freshwater and marine systems. Studies of the effect of chlorinated sewage effluents and cooling water from generating stations on marine organisms and ecosystems are summarized.

INTRODUCTION

Chlorine gas has seen industrial use since 1800 as a bleaching agent and has become one of the most versatile chemicals known. In freshwater it is well known as a disinfectant for drinking and recreational water, biocide for slime and fouling control, and treater of municipal wastes for pathogen control. In these applications, vast quantities of chlorine are used, and find their way through society's effluents to natural ecosystems. The toxicity desired in disinfection and biocide applications can continue with non-desirable effects to wildlife and their ecosystems. Recent findings of halogenated organics traceable in drinking water in 80 cities, underscore the need for responsible assessment of the management and effects of our chlorination processes, and the environmental costs incurred.

The State of Maryland is often used by planners as a minimodel for the United States. In the case of rate of chlorine use, some of the most accurate statistics exist for Maryland. Furthermore, resulting chlorination constituents from Maryland mostly drain into the Chesapeake Bay. An inventory of chlorine discharge from Maryland alone into the Chesapeake Bay, assuming no degradation, results in the statistic of 27 million pounds per year of chlorine from municipal treatment plants and 2.2 million pounds per year from power generation facilities. It would appear to the casual observer that without the action of degradation processes, these amounts would soon sterilize the bay. It is calculated (but still to be confirmed experimentally) that 1 percent of these totals may become halogenated organic compounds possibly persisting in marine ecosystems. Twenty-three other states border marine ecosystems where some form or another of chlorine discharge currently persists in one manner or another.

The purpose of this paper is to compile the scarce data presently available for chlorine effects upon aquatic life of estuarine and marine ecosystems. The chemistry of chlorine is briefly reviewed to point out some of the unique features of chlorination in marine waters. Although some data exists on effects of residual chlorine and a limited number of byproducts upon specific organisms, virtually no information exists on transport processes, persistence, bioaccumulation, and fate of halogenated compounds from chlorination processes.

CHEMISTRY OF CHLORINE

Chlorine is presently manufactured by a variety of methods, including:

the electrolysis of brine,

$$2NaCl + 2H_2O \xrightarrow{\text{electric current}} 2NaOH + Cl_2 + H_2$$

the salt process,

$$3NaCl + 4HNO_3 \rightarrow 3NaNO_3 + Cl_2 + NOCl + 2H_2O$$

and the hydrochloric acid oxidation process,

$$4HCl + O_2 \xrightarrow{450-600^\circ C} 2Cl_2 + 2H_2O.$$

Chlorine in Freshwater Systems

Chlorine gas dissolves rapidly in water and hydrolyses,

$$Cl_2 + H_2O \rightleftarrows HOCl + H^+ + Cl^-.$$

This hydrolysis is nearly complete and only when the pH is below 3.0, or the chlorine concentration over 1000 mg/l is there any measurable quantity of molecular chlorine present. The oxidizing capacity of chlorine is retained in the hydrolysis product, hypochlorous acid. Hypochlorous acid dissociates to form,

$$HOCl \rightleftarrows H^+ + ClO^-.$$

This reaction is pH dependent. For a neutral pH (7.0) at 20°C, the equilibrium is approximately 75 percent HOCl and 25 percent ClO^-. For a pH of 8.0, the reverse is true with approximately 25 percent HOCl and 75 percent ClO^- (Sawyer and McCarty, 1969).

The addition of hypochlorite salts to water forms hypochlorite ions followed by hypochlorous acid,

$$Ca(ClO)_2 = Ca^{++} + 2\,ClO^-,$$

and

$$H^+ + ClO^- \rightleftarrows HOCl.$$

If ammonia or organic amines are present in the water, they will react with hypochlorous acid to form chloramines,

$$NH_3 + HOCl = NH_2Cl + H_2O.$$

Like the ionization of hypochlorous acid to $H^+ + ClO^-$, the reaction rate between ammonia and hypochlorous acid is pH dependent, occurring most rapidly in solutions with a pH of 8.3. This reaction is also dependent upon temperature and the ratio of ammonia to hypochlorous acid.

Monochloramines react with hypochlorous acid to form di- and trichloramines,

$$NH_2Cl + HOCl = NHCl_2 + H_2O,$$

and

$$2NH_2Cl + HOCl = NCl_3 + H_2O.$$

Low pH favors a shift in equilibrium toward the formation of di- and trichloramines. Fair et al. (1948) determined that at pH 5.0, the ratio was 16 percent monochloramine and 84 percent dichloramine. For a pH of 8.0, the ratio was 85 percent monochloramine and 15 percent dichloramine. Trichloramine is found in significant quantities only at pH values of less than 4 (McKee and Wolf, 1963).

Table 1.—Summary of reactions of chlorine with organic compounds in freshwater (modified from Ingols et al. 1953)

Organic Substrate	Hypochlorous Acid	Monochloramine
Alanine	Pyruvic acid	Organic monochloramine
Cysteine	RSO_3H	RSSR
Glycylglycine	Oxidative	
Glycylglycylglycine	Hydrolysis and deamination	Terminal organic monochloramine
Tyrosine	Ketone	Organic monochloramine
Hemin	Violent change	Irreversible addition or oxidation

Ingols et al. (1953) determined that hypochlorous acid and monochloramine in freshwater will react with various organic constituents. Some of these reactions resulted in the formation of organic monochloramines although none were persistent, Table 1.

The formation of chlorinated organic compounds during chlorination of sewage effluents and power plant cooling waters has recently been documented (Jolley, 1973; Jolley et al. 1975). Isotopic ^{36}Cl tracers and high-resolution anion-exchange chromatography were used to separate over 50 chlorine containing constituents from chlorinated secondary effluents. Fifteen of these were tentatively identified and quantified, Table 2.

Table 2.—Tentative identifications and concentrations of chlorine containing constituents from chlorinated sewage effluents (modified from Jolley, 1973)

Identification	Conc. of Organic compound ug/L
5-Chlorouracil	4.3
5-Chlorouridine	1.7
8-Chlorocaffeine	1.7
6-Chloroguanine	0.9
8-Chloroxanthine	1.5
2-Chlorobenzoic acid	0.26
5-Chlorosalicylic acid	0.24
4-Chloromandelic acid	1.1
2-Chlorophenol	1.7
4-Chlorophenylacetic acid	0.38
4-Chlorobenzoic acid	0.62
4-Chlorophenol	0.69
4-Chlororesorcinol	1.2
3-Chloro-4-hydroxybenzoic acid	1.3
4-Chloro-3-methyl phenol	1.5

Chlorine in Marine Systems

Major sources of chlorine contamination in the marine environment are related to postchlorination of secondary sewage effluents with outfalls located on coastal and estuarine waters, and chlorination of seawater used for cooling of thermal electric generating plants (White, 1972, 1973; Markowski, 1959).

The addition of chlorine to seawater results in a complex series of chemical reactions; the most obvious one frees bromine,

$$Cl_2 + 2Br^- = 2Cl^- + Br_2.$$

This reaction goes to completion and is the basis for the manufacture of bromine from seawater (Lewis, 1966).

The industrial extraction of bromine from seawater requires that the pH be reduced below 3.0, so that molecular chlorine can release molecular bromine. The hydrolysis products from adding chlorine to seawater, HOCl and ClO^-, will also release bromine from the bromide ion in the form of hypobromous acid and hypobromite ion,

$$ClO^- + Br^- = BrO^- + Cl^-,$$

and

$$BrO^- + H^+ \rightleftarrows HOBr.$$

Houghton (1946) has also suggested that chlorination of water containing free ammonia and bromine may result in the formation of bromamines. Johanneson (1958) added chlorinated water to a sodium-ammonium salts solution buffered to pH 8.3. This resulted in the formation of monobromamine and some monochloramine. The addition of sodium hypochlorite solution produced mostly monochloramine. The hypochlorite in solution apparently reacts with both the bromine and ammonia,

$$ClO^- + Br^- = BrO^- + Cl^-,$$

and

$$ClO^- + NH_3 = NH_2Cl + OH^-.$$

Injection of chlorine gas may result in localized acidity, favoring the first reaction above, which is rapid at pH values of less than 8.0. The second reaction is favored when chlorine is added as sodium hypochlorite since there is no accompanying reduction in the normal pH of 8.0–8.3.

When ammonia is present in seawater, it will react with hypobromous acid to form monobromamine. Monobromamine in turn will react with hypobromite ion to form dibromamine,

$$NH_3 + HOBr = NH_2Br + H_2O,$$

and

$$NH_2Br + BrO^- = NHBr_2 + OH^-.$$

In addition, monobromamine at near neutral pH will form ammonium bromide which dissociates into ammonium ion and free bromine (Johanneson, 1960).

$$NH_2Br + H^+ \rightleftarrows NH_3Br^+$$

and

$$NH_3Br^+ \rightleftarrows NH_3 + Br^+.$$

Block and Helz (1975) have prepared a reaction series model to illustrate the theoretical degradation processes occurring after the addition of chlorine to natural, saline waters, Figure 1. Compounds in each successive level can give rise to ones on a lower level. In general, compounds occurring on lower levels will not contribute to the formation of those in the levels above.

The reaction occurring between levels I and II is a result of chlorine decay from a diatomic gas to hypochlorous acid, hypochlorite ions, and sodium hypochlorite. As pointed out by Moore (1951) and Lewis (1966), this reaction occurs rapidly and goes to completion within seconds after the addition of chlorine. The inclusion of sodium hypochlorite

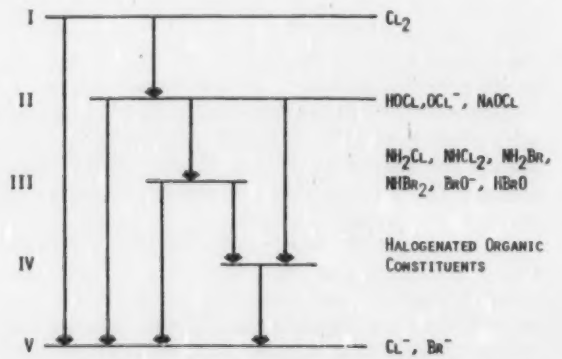

FIGURE 1.—Degradation processes for chlorine in saline waters (modified from Block and Helz, in preparation).

within level II is based on the results of work by Sugum and Helz (1976).

The chemical composition and abundance of products formed from level II to level III is a function of physical and chemical parameters of the water, including but not limited to temperature, pH, ammonia, and bromine, available as reaction components. In seawater it is possible that the predominant species would be bromamines, especially if NH_4^+ ions are less abundant than Br^- ions.

Level IV includes halogenated organic constituents which may be formed by level II or level III species, including chloramines, hypobromite and bromamines. The stable end products in level V occur through a diverse group of mechanisms taking place in steps I–IV.

Charge balance results in one atom of Cl passing from level I to level V to each atom passing from level I to level II. Reduction of hypochlorite by Br^- or Fe^{2+} and Mn^{2+} may release Cl^- from level II to level V. Movement of Cl^- from level III to level V can also occur in a number of ways; the most obvious, suggested by Laubusch (1971) involves the destruction of chloramines when the OCl^-/NH_4^+ ratio is large.

Some of the chlorinated organics identified by Jolley (1973) are persistent and the decay from level IV to level V is probably a slow process, relative to decay from levels I through III to level V.

TOXICITY OF CHLORINE IN ESTUARINE ENVIRONMENTS

The relative toxicity of chlorine in water is related to the amount and proportions of free and residual chlorine. Several investigators have found that free chlorine is generally more toxic to freshwater organisms than chloramines (Doudoroff and Katz, 1950; Merkens, 1958), even though the toxicity of the various forms of chlorine was of the same order of magnitude. Rosenberger (1971) and Basch and Truchan (1973), found that dichloramine was more toxic than monochloramine in freshwater. A comprehensive review paper by Brungs (1973) summarizes the toxic effects of residual chlorine on freshwater aquatic organisms.

In seawater, Holland et al. (1960) determined that dichloramine is apparently more toxic than monochloramine and that the chloramines were more toxic than free chlorine. These findings may reflect the complex chlorine-bromine reaction kinetics suggested by Johanneson (1958, 1960) and Lewis (1966).

Chlorine Toxicity to Marine Phytoplankton

The effects of chlorination and thermal pollution on phytoplankton productivity have been investigated in some detail, Table 3. Carpenter et al. (1972) observed an 83 percent decrease in the productivity of phytoplankton passed through the cooling system of a nuclear generating plant on Long Island Sound.

Intake water was chlorinated at a rate of 1.2 mg/l with a residual of 0.4 mg/l measured at the discharge. Addition of 0.1 mg/l chlorine at the intake with non-detectable residuals at the outfall decreased productivity by 79 percent. Essentially no decreases in productivity were observed when phytoplankton passed through the cooling system without addition of chlorine. Hirayama and Hirano (1970) measured the effect of chlorination on the photosynthetic activity of *Skeletonema costatum* and found that cells were killed when subjected to 1.5 to 2.3 mg/l chlorine for 5 and 10 minutes.

Gentile (1972, 1973 unpublished data, Environmental Research Laboratory, Narragansett) observed a 55 percent decrease in the ATP content of marine phytoplankton exposed to 0.32 mg/l residual chlorine for two minutes and a 77 percent decrease after 45 minutes of exposure to chlorine concentrations as low as 0.01 mg/l. A 50 percent depression in the growth rates of 10 species of marine phytoplankton exposed to chlorine concentrations ranging from 0.075 to 0.25 mg/l for 24 hours was also measured.

Morgan and Stross (1969) used photosynthetic rates to evaluate the response of estuarine phytoplankton passed through the cooling system of a steam electric power station on the Patuxent River, Md. The photosynthetic rate increased with an 8°C rise in temperature when ambient water temperatures were 16°C or less. Inhibition occurred when ambient temperatures were above 20°C. In a related study, conducted at the same site, Hamilton et al. (1970) measured a 91 percent decrease in primary productivity during intermittent chlorination.

Chlorine Toxicity to Invertebrates

Muchmore and Epel (1973) investigated the effects of chlorination of wastewater on fertilization in marine invertebrates, Table 4. Unchlorinated sewage (from the Pacific Grove, Calif.) was a weak inhibitor of fertilization in the sea urchin, *Strongylocentrotus purpuratus*. Exposure of gametes of the

Table 3.—Summary of toxic effects of chlorinated wastes and water on marine phytoplankton

Species	Toxicant	Measured Residual Chlorine mg/l	Duration of Test	Effect(s)	Reference
Phytoplankton	Cl_2 injection	0.05–0.40	12 hrs + 4 hrs incubation	50–98% loss of productivity	Carpenter et al. (1972)
Chlamydomona sp.	Hypochlorite solution	0.69–12.9	5 min	Reduced growth rate	Hirayama and Hirano (1970)
Skeletonema costatum		0.18–2.4	5 min	None up to 0.29 mg/l; greater amts. inhibited growth	
Phytoplankton	Hypochlorite solution	0.32	2 min	55% decrease in ATP	Gentile et al. (1972, 1973)
		0.01	45 min	77% decrease in ATP	
		0.075–0.25	24 hrs	50% decrease in growth	
Phytoplankton	Cl_2 injection		15 min	91% reduction in photosynthesis	Hamilton et al. (1970)

Table 4.—Summary of toxic effects of chlorinated wastes and water on marine invertebrates

Species	Toxicant	Measured Residual Chlorine mg/l	Duration of Test	Effect(s)	Reference
Strongylocentrus purpuratus (gametes)	Chlorinated sewage effluents	0.02	5 min	None	Muchmore and Epel (1973)
		0.11	5 min	100% inhibition of fert.	
Urechis caupo (gametes)		0.2	5 min	22% inhibition of fert.	
		1.0	5 min	100% inhibition of fert.	
Phragmatopoma californica (sperm)		0.2	5 min	22% loss of motility	
		1.0	5 min	86% loss of motility	
Ostrea edulis	Residual chlorine	10.0	48 min + 10 C	None	Waugh (1964)
Elminius modestus		2.0	10 min	Death and inhibited growth	
		5.0	3 min	None	
Balanus sp.	Cl_2 injection	2.5	5 min	80% mortality	McLean (1972, 1973)
Acartia tonsi		2.5	5 min	90% mortality	
Melita nilida		2.5	5 min	Near 100% mortality 96 hrs after exposure	
Palaemonetes pugio		2.5	5 min		
Bimaria franciscana		4.5	4 days	None	
Anemones	Residual chlorine	10.0	1, 2, 4, 8 hrs/day for 10 days	None	Turner et al. (1948)
		2.5	8 days	100% mortality	
		1.0	15 days	100% mortality	
Mussels		10.0	1, 2, 4, 8 hrs/day for 10 days	None	
		2.5	5 days	100% mortality	
		1.0	15 days	100% mortality	
Barnacles		10.0	1, 2, 4, 8 hrs/day for 10 days	95–100% mortality	
		2.5	4 days	100% mortality	
		1.0	7 days	100% mortality	
Mytilus edulis	Cl_2 injection	0.02–0.05	A few hrs	Detachment and migration	James (1967)

sea urchin to a 10 percent unchlorinated sewage-seawater mixture typically reduced fertilization success by 20 percent. A 0.5 percent dilution of moderately chlorinated sewage (11 mg/l TRC undiluted), significantly reduced fertilization. It was also determined that chlorination had more effect on sperm cells than on eggs. Eggs incubated for 5 minutes in a 0.77 mg/l hypochlorite solution and subsequently washed to remove the hypochlorite, showed no reduction in fertility. Incubation of sperm at a 0.07 mg/l hypochlorite concentration resulted in a loss of fertilization ability. This was attributed to a loss of sperm motility which was not restored after washing to remove the hypochlorite. Gametes of the echiuroid, *Urechis caupo*, and sperm of the annelid worm, *Phragmatopoma californica*, were not as sensitive to chlorine toxicity.

A number of power plant related studies have been conducted to determine the effect of chlorination of seawater on fouling organisms. Waugh (1964) observed no significant difference in the mortality of oyster larvae, *Ostrea edulis*, exposed to 5 mg/l

chlorine for 3 minutes at ambient temperature, compared to control mortality. Exposure of larvae to thermal stress (10°C above ambient) and 10 mg/l chlorine for 6 to 48 minutes also had no significant effect on survival 64 hours after treatment. Barnacle nauplii, *Elminius modestus*, showed more acute sensitivity to chlorination. Residual chlorine readings in excess of 0.5 mg/l caused heavy mortality and reduced growth for survivors.

McLean (1973) simulated the conditions encountered by marine organisms passing through a power plant on the Patuxent River, Md. Intake chlorination to 2.5 mg/l residual, entrainment for approximately 3 minutes and sustained exposure to elevated temperatures for up to 3 hours were used as experimental parameters. While barnacle larvae, *Balanus sp.* and copepods, *Acartia tonsi*, were not affected by a 3 hour temperature stress of 5.5 and 11°C above ambient, exposure to 2.5 mg/l chlorination for 5 minutes at ambient temperatures caused respective mortality rates of 80 and 90 percent. The amphipod, *Melita nitida*, and the grass shrimp, *Palaemonetes pugio*, showed a delayed death response after exposure to 2.5 mg/l for 5 minutes. Nearly 100 percent mortality was observed for both species 96 hours after exposure to the chlorination. McLean (1972) showed that established colonies of the euryhaline colonial hydroid, *Bimeria franciscana*, were not greatly affected by 1 and 3 hours of exposure to 4.5 mg/l chlorination.

Turner et al. (1948) determined that continuous treatment of seawater conduits with 0.25 mg/l chlorine prevented fouling during a 90 day interval when the flow velocity was 52 cm/second or less. Intermittent treatment with 10 mg/l "residual chlorine" for 8 hours a day was ineffective in preventing fouling by anemones, mussels and barnacles.

James (1967), working in Great Britain, observed that chlorination levels of 0.02 and 0.05 mg/l caused detachment and movement of mussels in the direction of water flow through an aquarium with eventual elimination of the mussels. He concluded that the most effective way to prevent fouling by mussels was not to kill, but to discourage settling in cooling water systems by continuous low level chlorination.

Markowski (1960) compared the occurrence of marine organisms on concrete slabs placed in the intake and outfall canals of an electric generating plant. Chlorine was injected into the condensors of this plant for two hours a day at a concentration between 1 and 2.5 mg/l. No vegetation was observed growing in the intake canal where dense animal populations occurred (predominantly invertebrates, Coelenterata and Polyzoa). The outfall canal contained a prolific growth of algae, *Enteromorpha sp.* but fewer invertebrates. *Balanus improvisis*, which was collected with some regularity from the intake canal was never observed in the outfall canal. The mollusk, *Eubranchus sp.* was more abundant on the intake slabs than in the outfall.

Chlorine Toxicity to Estuarine Fish

Tsai (1968, 1970, 1975) has observed decreases in the abundance and occurrence of brackish water fish species in certain areas of the Upper and Little Patuxent Rivers receiving chlorinated sewage effluent. Tsai suggests that chlorinated sewage effluent may also block the upstream migration of such semi-anadromous species as the white catfish and white perch. He attributed the blocking effect to chlorination products rather than reduced dissolved oxygen or pH resulting from organic decomposition of the effluent, Table 5.

Tsai (1973) measured the diversity index of fish upstream and downstream of 98 sewage treatment plants in Virginia, Maryland and Pennsylvania. Sewage treatment plants were categorized as Type I engineering facilities (sludge activation, aeration, sedimentation and filtration) with effluent chlorination; Type II, engineering facilities with chlorination and an effluent holding lagoon; and Type III, engineering facilities with a lagoon and effluent chlorination at the lagoon outlet. Reductions in the number of fish, number of species and the species diversity index were significant downstream of Type I and III plants. These reductions were attributed to total residual chlorine levels and turbidity. Diversity indices showed no significant changes in downstream areas associated with Type II plants.

Massive fish kills occurred on the James River, Va., during May–June 1973 (Virginia State Water Control Board, 1974). Species affected by the kill included spot, *Leiostomus xanthurus*; white perch, *Morone americana*; bluefish, *Pomatomus saltatrix*; grey seatrout, *Cynoscion regalis* and menhaden, *Brevoortia tyrannus*. A majority of the fish kill in the James River occurred adjacent to sewage treatment plants. Chlorination oxidation levels as high as 0.7 mg/l were observed in the James. Effluents from both plants showed more than 3.0 mg/l.

Distress symptoms of fish dying included spiral swimming patterns, broken vertebral columns, listless floating, inverted swimming, distension of the air bladder in some, loose body scales, mucous on the skin and hemorrhaging along the fins and body surface.

Table 5.—Summary of toxic effects of chlorinated wastes and water on marine and freshwater fishes

Species	Toxicant	Measured Residual Chlorine mg/l	Duration of Test	Effect(s)	Reference
Freshwater and brackish fishes	chlorinated sewage effluents	0.6–2.0	Long term	Decreased popn. size and diversity	Tsai (1968, 1970, 1973)
L. xanthurus Morone sp. Polatomus saltatrix C. regalis Brevoortia tyrannus	chlorinated sewage effluents	0.07–0.28	May–June, 1973	Probable kill 5–10 million fish	Virginia State Water Control Board (1974)
L. xanthurus	sodium hypochlorite	0.09 0.14 0.28	96 hrs 24 hrs 6 hrs	50% mortality 50% mortality 50% mortality	VIMS for VSWCB (1974)
O. nerka O. gorbuscha (freshwater)	chlorinated sewage effluents	0.02–0.26 0.16	24 hrs 72 hrs	100% mortality 100% mortality	Servizi and Martens (1974)
O. gorbuscha O. tshawytscha	Residual chlorine	0.5 0.5	30 min + 10 C 10 min + 10 C	50% mortality 50% mortality	Stober and Hanson (1974)
Morone americana	residual chlorine	0.08	10 min	Avoidance	Holdrim et al. (1974)
Menidia menidia		0.08	10 min	Avoidance	
F. heteroclitus		0.03	10 min	Avoidance	
Trinectes maculatus		0.03	10 min	Avoidance	
Pleuronectes platessa (eggs)	free chlorine	0.04–0.08 0.62 0.10	8 days 72 hrs 96 hrs	None 50% mortality 50% mortality	Alderson (1972)
(larvae)		0.032 0.026	48 hrs 96 hrs	50% mortality 50% mortality	
Cyprinus carpio	4-Chlorouracil 5-Chlorouracil (0.001 mg/l)	----------	3–7 days	Reduced hatch	Gehrs et al. (1974)

Live box tests conducted adjacent to the James River sewage treatment plant (STP) demonstrated a correlation between rates of effluent chlorination and mortality of juvenile spot and croaker. With an average daily chlorine feed of 1,200 pounds (total flow of water was approximately 10 mgd during tests) and a measured activated oxidant level of 3.0 mg/l, caged fish suffered 100 percent mortality within 20 hours. After a cutback to a chlorine feed rate of approximately 400 pounds per day, only 20 percent mortality was observed among caged fish after 20 hours.

On-site aquaria tests confirmed the results of the cage tests. Water from an area adjacent to the outfall of the James River (STP) was pumped through aquaria containing juvenile spot. Mortalities ranged from 91 to 100 percent after 40–85 minutes of exposure prior to the cutback in chlorination. After chlorination rates were reduced, mortalities were 0–26 percent after 120 minutes of exposure.

Continuous flow laboratory bioassays were also conducted. The 96 hour LC_{50} for juvenile spot was estimated at 0.09 mg/l. The estimated 24 hour LC_{50} was 0.14 mg/l and the 6 hour LC_{50}, 0.28 mg/l.

Separate field studies on the spot, *Leiostomus xanthurus*, found up to 40 percent of juveniles from the 1973 year class exhibited deformities in the vertebral column. These abnormal forms are identifiable as a distinct year class in 1975 population samples from the James River, (Labbish Chao, personal communication).

A study of the effect of chlorinated sewage effluents on sockeye salmon, *Onchorhynchus nerka*, and pink salmon, *O. gorbuscha*, has been conducted by Servizi and Martens (1974). They used three study sites to conduct cage bioassays. The first, Site I, was adjacent to a primary treatment plant with effluents chlorinated following settling and discharged through a 600-foot pipeline directly into the receiving stream. Site II was on a stream receiving wastes from an activated sludge plant in which chlorinated effluents were discharged into a large effluent holding lagoon and retained from 30 to 60 days. Site III was located on a stream receiving effluents which were chlorinated as they left a non-aerated lagoon.

Measured chlorine residuals in the receiving stream at Site I ranged from 0.02–0.26 mg/l. These

concentrations resulted in 100 percent mortality of caged sockeye fingerlings placed 30, 60 and 250 feet below the effluent discharge point. Additional tests indicated that the primary effluent without chlorination was also toxic. However, fish exposed to the unchlorinated effluent lived 10 times longer than ones exposed when effluents were being chlorinated. Toxicity of the unchlorinated effluents was attributed to MBAS and ammonia.

Tests at Site II indicated that chlorinated effluents retained for 30 to 60 days were not toxic to sockeye fingerlings and alevins and pink salmon alevins after 26 days of exposure.

In tests at Site III, with fingerling sockeye salmon, chlorinated sewage effluents (measured 0.85 mg/l) resulted in 50 percent mortality after 48 minutes. Fifty percent mortality occurred after 13 hours of exposure to the unchlorinated effluents. Sublethal exposures of fingerling sockeye salmon to the effluents from Site III (1–3 hours of exposure to 0.22 mg/l) resulted in gill damage, including hyperplasia, swollen epithelial cells, and separation of epithelium from pillar cells.

The toxicity of chlorine and heat to pink, *Oncorhynchus gorbuscha*, and chinook salmon, *O. tshawytscha*, has been determined by Stober and Hanson (1974). Juveniles of each species were tested in seawater at five chlorination concentrations, ranging from 0.05–1.0 mg/l, and four temperatures from t 0–10°C. Salmon were exposed to each matrix for 7.5–60 minutes. A decrease in the tolerance of both species to chlorination was observed with increased temperature and exposure time. The most toxic effect was observed at a t of 9.9–10°C where the LT_{50} (lethal time for 50 percent mortality) ranged from approximately 10 minutes at 0.5 mg/l for chinooks to 80 minutes for pinks.

Meldrim et al. (1974) in flowing water bioassays studied the effect of chemical pollutants on estuarine organisms. They found that white perch, *Morone americana*, consistently avoided levels as low as 0.08 mg/l at temperatures from 7–17°C. Silversides, *Menidia menidia*, also avoided 0.08 mg/l at temperatures from 8–28°C but showed a preference for 0.08 mg/l when fish acclimated to 7°C were exposed at 12°C. Mummichogs, *Fundulus heteroclitus*, and hog chokers, *Trinectes maculatus*, avoided levels as low as 0.03 mg/l.

Alderson (1972) found that the 48 and 96 hour Tl_m of free chlorine for plaice larvae, *Pleuronectes platessa*, was 0.032 and 0.026 mg/l respectively. Eggs were not affected when exposed to 0.075 and 0.04 mg/l free chlorine for 8 days, indicating that the egg membrane gives considerable protection over long periods. The 72 and 192 hour Tl_m for eggs was 0.7 and 0.12 mg/l respectively.

Gehrs et al. (1974) tested the sensitivity of carp eggs, *Cyprinus carpio*, to two of the compounds identified by Jolley, 4-Chlororesorcinol and 5-Chlorouracil. Significant reductions in the hatchability of non-water hardened carp eggs were observed in concentrations of each compound as low as 0.001 mg/l.

In California, Young (1964) observed tumor-like sores around the mouth of white croakers, *Genyonemus lineatus*, collected near the Hyperion sewage outfall in Santa Monica Bay. While there was no direct evidence to link the occurrence of lesions with chlorinated sewage effluents, a general decline in fitness of croakers and other species found in close proximity to the outfall area was observed.

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THE IMPACT OF SYNTHETIC ORGANIC COMPOUNDS ON ESTUARINE ECOSYSTEMS

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ABSTRACT

The presence and effects of synthetic organic compounds is briefly reviewed with reference to the recent literature on the estuarine ecosystem. Pesticides and industrial toxicants are discussed in general with some attention given to synergistic and modifying effects. Recommendations for future research are made which include elucidating the effects of synthetic organics at the ecosystem level.

INTRODUCTION

For the purposes considered herein, the term "synthetic organic compounds" refers to manmade compounds and includes pesticides, polychlorinated biphenyls (PCB's), hexachlorobenzene (HCB) and phthalate esters (PAE's) as well as toxic contaminants of some of these, like chlorinated dibenzodioxins and dibenzofurans.

The estuarine ecosystem has been variously defined but for the sake of simplicity it will be considered as that zone where fresh and salt water mix. This estuarine ecosystem serves a vital function in that most marine finfish and shellfish depend on a high quality estuary for some critical portion of their life history (Clark, et al., 1969; Douglas and Stroud, 1971). In addition, many salmonids and other anadromous fishes spend a variable amount of time in this habitat before ascending the rivers to spawn.

Unfortunately, the oceans are the recipients and ultimate accumulation sites for persistent pollutants like organochlorines (Dustman and Stickel, 1966; Risebrough, et al., 1972). In fact, an estimated 25 percent of all DDT applied to the land has found its way to the sea (S.C.E.P., 1970). Risebrough and his co-workers (1968a) indicate that 11 tons of DDT per year are transported down the Mississippi River to the Gulf of Mexico alone! Because of their unique physical and chemical characteristics, estuaries tend to be toxicant traps. The detritus which forms the base of the estuarine food chain may contain up to 50 ppm total DDT. Odum, et al., (1969), and Woodwell, et al., (1967), estimated that total estuarine ecosystem levels as high as 14.7 kg/hectare were possible.

DDT and other synthetic organics are termed toxic when, because of their physical or chemical properties, they interfere with normal biological functions. The interference can occur at any level, whether it be as subtle as pesticide-induced decreased growth in oysters or as gross as reproductive failure in bald eagles or mass fish mortality. Naturally-occurring toxic substances include resin from certain plants and the toxins associated with red tide organisms. By far, however, most deleterious substances find their origin with modern-day man and his efforts to promote "progress."

A logical breakdown of synthetic organic compounds which are considered in this paper along with available production and/or consumption information follows.

1. Pesticides are chemicals which kill organisms identified as "pests" and include insecticides, fungicides, piscicides, herbicides, miticides, etc. *Insecticides* are commonly broken down into: (a) chlorinated hydrocarbons (organochlorines), like DDT, aldrin, dieldrin, heptachlor, toxaphene, and chlordane; (b) organophosphates, like malathion, parathion, diazinon, and guthion; and (c) carbamates, like Sevin and zectran. *Fungicides* include dithiocarbamates (e.g., ferbam and ziram), nitrogen containing compounds (e.g., phenylmercuric acetate), triazines, quinones, heterocyclics, and inorganics like the heavy metals. Hexachlorobenzene (C_6Cl_6 or HCB) is a fungicide but is, in addition, used in organic synthesis processes. *Herbicides* are quite varied with the most common being the phenoxy acids like 2,4-D and 2,4,5-T. Frequently used aquatic herbicides include endothal and diquat which are often used in combination with a surfactant (like a detergent).

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Table 1.—U.S. production of synthetic organic pesticides by class, 1967–1972*. In thousands of pounds.

	1967	1968	1969	1970	1971	1972
Fungicides	177,886	190,773	182,091	168,470	180,270	170,569
Herbicides	439,965	499,514	423,840	434,241	458,849	481,618
Insecticides, fumigants, rodenticides†	503,796	581,619	580,884	495,432	564,818	569,157
Total	1,121,647	1,271,906	1,186,815	1,098,143	1,203,937	1,221,344

* Fowler, 1974.
† Includes small quantity of synthetic soil conditioners; does not include the fumigants carbon tetrachloride, paradichlorobenzene or inorganic rodenticides.

The U.S. production of the major synthetic organic pesticides is reproduced in Table 1. In 1971, the production of synthetic organic insecticides in the United States climbed nearly 14 percent from the year before, reaching 557.7 million pounds, third highest on record (Fowler, 1973). Insecticides accounted for 49 percent of the tonnage of synthetic pesticides produced. As one can see in Table 1, the trend was reversed for 1972.

Table 2 reveals the domestic disappearance of selected pesticides for the years 1966 through 1971. Except for the aldrin-toxaphene group, there is a fairly consistent downward trend. Domestic disappearance of DDT, for instance, was 18.2 million pounds in 1971, down more than 28 percent from 1970. The consumption of the aldrin-toxaphene group continued its rise during 1972. Sales for that group (not including Strobane®) soared to 140 million pounds for 1972 (U.S. Tariff Commission, 1974).

2. "Industrial Toxicants" is a catch-all term that has been variously subdivided. *Polychlorinated biphenyls* (PCB's) are chlorinated compounds which find use in almost every sector of modern man's world and have recently come under close scrutiny (Peakall and Lincer, 1970). In the past, they have been used in such diverse products as printer's ink to swimming pool paint; however, a voluntary curtailment by Monsanto has restricted their use.

Table 2.—Domestic disappearance of selected pesticides at producers' level, United States, 1966–1971. In thousands of pounds. (Fowler, 1973).

Pesticide	1966*	1967*	1968†	1969†	1970†	1971†
Aldrin-toxaphene group**	86,646	86,289	38,710	89,721	62,282	85,005
Calcium arsenate	2,942	2,329	1,992	2,117	2,900	2,457
Copper sulfate	104,020	85,274	87,452	99,840	77,344	70,272
DDT	45,603	40,257	32,753	30,256	25,457	18,234
Lead arsenate	6,944	6,152	4,747	7,721	5,860	4,142
2,4-D	63,903	66,955	68,404	49,526	46,942	32,174
2,4,5-T	17,080	15,381	15,804	3,218	4,871	1,389

* Year ending September 30.
† Year ending December 31.
** Includes aldrin, chlordane, dieldrin, endrin, heptachlor, Strobane® and toxaphene.

Phthalate esters (PAE's) were introduced in the 1920's to overcome the problems of camphor in the plasticizer industry. Major uses of PAE's include construction products, automobile and home furnishings, clothing, food coverings and medical products. Phthalates are also found in biochemical pathways and several natural products such as poppies and tobacco leaves (Graham, 1973; Mathur, 1974). The documentation that PAE's were readily assimilated into blood from plastic storage bags and other medical devices was the original basis for the fear that the human population might be continuously exposed (Anonymous, 1973).

PCB's and PCT's (polychlorinated terphenyls) are produced under the trade name Aroclor® by Monsanto in the United States. PCB production peaked during the period 1967–1970 (Table 3). PCT production shows a similar, but later, production peak during 1970–1971. PCT's are no longer being produced and the manufacture of PCB's is directed exclusively towards the heat transfer, transformer, and capacitor sales categories. In an effort to overcome some of the potential environmental problems

Table 3.—Production of polychlorinated biphenyls (PCB's) and polychlorinated terphenyls (PCT's) by Monsanto Industrial Chemicals Company for years 1959–1973. (Pers. comm., W. B. Papageorge).

Year	U.S. Production (Thousands of Pounds)	
	PCB's	PCT's
1959	*	2,996
1960	37,919	3,850
1961	36,515	2,322
1962	38,353	4,468
1963	44,734	4,920
1964	50,833	5,288
1965	60,480	6,470
1966	65,849	9,190
1967	75,309	9,450
1968	82,854	8,870
1969	76,389	11,600
1970	85,054	17,768
1971	34,994	20,212
1972	38,600	6,134
1973	42,178	**

* Data unavailable.
** Production terminated in April, 1972.

of existing biphenyls, Aroclor 1016 was produced. Approximately 23.5 million pounds of Aroclor 1016 were sold domestically in 1973. The 1973 sales for Aroclors 1221, 1242 and 1254 were recorded at 0.04, 6.20 and 9.98 million pounds, respectively. All other PCB's showed no domestic sales (personal communication, W. B. Papageorge).

"Plasticizers" are obviously produced by a variety of manufacturers, however, phthalates (DOP, DIOP, DIDP and linear) are the major groups consumed (Table 4). During 1972, production of phthalic anhydride esters totaled 1,145,693 pounds and sales followed closely at 1,138,493 pounds (U.S. Tariff Commission, 1974).

Table 4.—Consumption of plasticizers by type (in thousand metric tons)*.

Plasticizer	1972	1973	1974
Adipates	28.0	28.4	27.3
Azelates	5.8	7.2	7.3
DOP/DIOP/DIDP	345.0	379.5	363.6
Epoxy	50.0	56.8	59.1
Linear phthalates	109.0	125.5	143.2
Polyesters	22.7	25.4	24.1
Trimellitates	8.1	8.5	10.5
Others	116.0	113.0	113.6
Total	679.6	744.3	748.7

* Source: Anonymous, initialed R. M. (1974).

PRESENCE OF SYNTHETIC ORGANICS IN ESTUARIES

Pesticides

Considering only the organochlorine pesticides, DDE (the major breakdown product of DDT) is probably the most widely distributed in fish and wildlife (see Appendix A). Being lipophilic (i.e., "fat-loving"), DDE like other organochlorines is not very soluble in water but accumulates in the fat of organisms (for overview, see Table 1 in reference entitled EPA, no date). Organochlorine pesticides are passed from prey to predator with little lost by way of excretion. This biological magnification with each transfer from one food level (i.e., trophic level) to the next results in animals at the tops of food chains acquiring inordinate amounts of these poisons (Woodwell, et al., 1967). For instance, DDE concentration reached 1,100 ppm (parts per million) in the fat of brown pelican eggs collected off the coast of California and 1,000 ppm in the eggs of the white-tailed eagle collected in the Baltic (Risebrough, et al., 1972).

Organochlorine pesticides are readily accumulated by shellfish and this characteristic has been taken advantage of to characterize the geographic distribution of pesticide contamination. As part of the National Pesticide Monitoring Program by EPA (Butler, 1973), shellfish were collected from coastal zones of the United States. Analyses of over 8,000 samples for 15 persistent organochlorines showed that DDT-type residues were ubiquitous, with the maximum DDT level at approximatlely 5 ppm. Dieldrin was the second most commonly detected compound with a maximum of 0.23 ppm. Other organochlorine pesticides found occasionally which are also extremely toxic to estuarine life, included endrin, mirex and toxaphene.

Although most organophosphate and carbamate pesticides are advertised as short-lived, there is evidence that some may not be. In an application of carbaryl (Sevin) at rates comparable to those used to control oyster pests, the chemical could still be detected in the mud 42 days post-treatment (Karinen, et al., 1967). Similarly, 14 days after a standard ground application of malathion, the organophosphate could still be found in the estuarine plant *Juncus* (Tagatz, et al., 1974).

The fungicide hexachlorobenzene (HCB), has recently been reported in several species of freshwater and some species of anadromous fish including coho salmon from Michigan and striped bass from Maryland and Florida (Johnson, et al., 1974).

Industrial Toxicants

Polychlorinated biphenyls (PCB's) are as widely distributed as DDT. Because of similar molecular shape and composition, the physical and chemical properties of PCB's also confer the same lipophilic characteristic that allows biological accumulation and food chain magnification.

Estuarine organisms like fiddler crabs and shrimp readily pick up PCB's from the sediments (Nimmo, et al., 1971a) and filter-feeding oysters accumulate these chemicals, like organochlorine pesticides, from the water (Lowe, et al., 1972).

Like the organochlorine pesticides, PCB's accumulate to high levels in organisms representing the tops of food chains. Fat from the eggs of California brown pelicans contained 200 ppm PCB's while similar samples from the Baltic white-tailed eagle contained 540 ppm (Risebrough, et al., 1972).

An ever-increasing list of industrial toxicants has been found in our waterways. Phthalate esters have been found in water collected from the Charles River in New England. Levels of 0.88–1.9 ppb were reported with higher levels associated with increasing distances upstream (Hites, 1973). Mayer, et al., (1972), reported on PAE's in selected samples from

North America. They found from 0.09 ppb DNBP (di-n-butyl phthalate) in Missouri River water to 200 ppb in Mississippi River channel catfish and 500 ppb in tadpoles. Similar values for another phthalate, DEHP (di-2-ethylhexyl phthalate), were 4.9, 400 and 300 ppb. These residue levels were roughly comparable to PCB levels in the same samples.

Although the above rivers drain directly into estuaries and one suspects that phthalates, like other adsorbed toxicants, would "salt out" upon reaching the saline environment, apparently no published research on phthalates has been directed towards that habitat.

Although the preliminary work of Bowes, et al., (1973), was directed at determining levels of chlorinated dibenzofurans and dibenzodioxins in wildlife populations exhibiting embryonic mortality, it did not reveal either of these two compounds. However, they reported hexachloronaphthalene in gull eggs but no chlorinated compounds of interest in sea lion samples.

BIOLOGICAL EFFECTS OF SYNTHETIC ORGANICS ON ESTUARINE LIFE

Pesticides

Organochlorine insecticides have been shown to interfere with almost every level of biological function tested in marine life (see Appendix B). Levels of DDT in the water as low as 0.001 ppm caused marked reduction in oyster growth (Butler, 1966a) and high levels of organochlorines have been associated with teratogenic effects in terns (Hays and Risebrough, 1972) and premature births in marine mammals (Delong, et al., 1973).

Some organochlorines, like Mirex, a chemical used to control the imported fire ant, *Solenopsis saevissima*, in the southeastern states, are particularly toxic to estuarine organisms. For example, juvenile shrimp and crabs died when exposed to one particle of mirex bait; and 1 ppb (part per billion) mirex in seawater killed 100 percent of the shrimp exposed (Lowe, et al., 1971a). Similarly, 0.1 ppm dietary dieldrin brought about maladaptive behavior in fiddler crabs (Klein and Lincer, 1973).

Some urea herbicides, like Diuron, significantly inhibit the growth of marine algae at levels as low as 1 ppb (Walsh and Grow, 1971) and a few parts per million of DDT, dieldrin or endrin is enough to reduce phytoplankton photosynthesis (Wurster, 1968; Menzel, et al., 1970).

Hexachlorobenzene has been shown to be especially toxic to birds under laboratory conditions (Vos, et al., 1968), but no tests on estuarine species have been reported to the author's knowledge.

Table 5.—Relative sensitivity of typical estuarine organisms to three major groups of pesticides. Higher numbers reflect greater sensitivity. Reworked from Butler, 1966b.

Organism	Pesticide Type		
	Herbicides	Organophosphates	Organochlorines
Plankton	1	0.5	3
Shrimp	1	1,000	300
Crab	1	800	100
Oyster	1	1	100
Fish	1	2	500

The sensitivity of a particular taxonomic group to any particular toxicant will vary appreciably. Although toxic to crustaceans, the carbamate Sevin is fairly nontoxic to fish and mammals (Lowe, 1967). In very general terms, Table 5 (reworked from Butler, 1966b) displays the relative toxicities of different pesticide groups to estuarine fauna.

In a toxicity test which included 12 insecticides and seven species of estuarine fish, the descending order of toxicity was: endrin, DDT, dieldrin, aldrin, dioxathion, heptachlor, lindane, methoxychlor, Phosdrin, malathion, DDVP, and methyl parathion (Eisler, 1970). For a more comprehensive listing of the toxic effects on estuarine life, by pesticide, the reader is encouraged to read Appendix Table 3 of EPA, no date.

California seems to have taken the lead in 1963 in describing the presence and effects of pesticides relative to water quality criteria (McKee and Wolf, 1963). This precipitated many studies and many questions. Perhaps the most important question a decision-making politician or coastal-zone administrator ought to ask with reference to toxic discharges is "How much should be allowed in our waters and what chemicals should not be applied at all near the estuaries?" Attempts have been made to answer these and similar questions. The National Technical Advisory Committee to the Secretary of the Interior (1968) zoned in on this topic and recommended that the following organochlorines not be applied near the marine habitat because of their extreme toxicity:

Aldrin
BHC
Chlordane
Endrin
Heptachlor
Lindane
DDT
Dieldrin
Endosulfan
Methoxychlor
Perthane
TDE
Toxaphene

Mirex also has been shown to be exceptionally toxic to estuarine invertebrates like shrimp and should be considered in this category. Hexachlorobenzene is particularly toxic to birds (Vos, et al., 1968) and deserves special attention around rookeries.

A similar list for organophosphates included:

Coumophos	Fenthion	Parathion
Dursban	Naled	Ronnel

The above organochlorines and organophosphates are acutely toxic at concentrations of 5 mg/l or less and should not be permitted to exceed 50 nanograms/l. The next group they discussed is generally not quite as toxic but should not be allowed to exceed 10 mg/l in estuarine waters. This group included:

Arsenicals	2,4,5-T compounds
Botanicals	Phthalic acid compounds
Carbamates	Triazine compounds
2,4-D compounds	Substituted urea compounds

This kind of information and guidance as to allowable levels of these and most other common toxicants, including radionuclides, heavy metals, PCB's, et cetera, is presently being updated by the Environmental Protection Agency (see National Academy of Science and National Academy of Engineering, 1972).

Industrial Toxicants

A great deal of research has been carried out on the effects of PCB's on estuarine life (Appendix B). Perhaps most of it has been done at the EPA Gulf Breeze Laboratory. PCB's have been shown to significantly decrease oyster growth at levels as low as 5 ppb (Lowe, et al., 1972) and be lethal to shrimp at 1 ppb (Nimmo, et al., 1971b). Duke, et al. (1970) showed that crabs concentrated the PCB Aroclor 1254 and 72 percent of the shrimp exposed to 5 ppb died after day 10. Hansen, et al. (1974a) demonstrated that estuarine fishes and shrimp displayed varying degrees of avoidance to the same PCB at levels 0.001 to 10 ppm. Bioassays with Aroclor 1254 indicated that 5 ppb caused mortality to estuarine fish and the effect was delayed (Hansen, et al., 1971). In response to the change in emphasis of PCB production and subsequent increase in Aroclor 1016 manufacture, Hansen and co-workers (1974b) established the acute 96-hour LC_{50}'s for estuarine shrimp, fish, and oyster.

The biochemical effects of PCB's have also come under scrutiny. Keil, et al. (1971) tested the effects of Aroclor 1242 (0.01–0.1 ppm) on marine diatoms and found that it inhibited growth, RNA synthesis and chlorophyll production. Aroclor 1221 has been shown capable of impairing osmoregulation in the killifish at relatively high levels (7.5–75 ppm) by Kinter, et al., (1972).

Although no work has apparently been done on the effects of PCB's on estuarine fish-eating birds, some data are available on ducks. Friend and Trainer (1970) showed a marked influence of Aroclor 1254 on the duck's susceptibility to viral infection. Heath, et al. (1972), testing a series of PCB's, revealed that toxicity was positively correlated with degree of chlorination and Haegele and Tucker (1974) established the effect of 1254 on eggshell thinning.

Very little toxicological work has been done with dioxins, dibenzofurans, and phthalates and nothing has been directed at the estuarine habitat, to the author's knowledge. Miller, et al. (1973) reported on the effects of tetrachloro-dibenzo-dioxin (TCDD) on various aquatic organisms. Approximately 50 percent of the young coho salmon exposed to 131 mg/l died by day 20. They also showed a marked growth inhibition by TCDD on both salmon and rainbow trout.

Zitko and his colleagues (1973) reported on the acute and chronic oral toxicity of chlorinated dibenzofurans to immature brook trout. They concluded that 2,8-dichlorodibenzofuran has a low acute toxicity to that species since even a high level of 122 mg/kg produced no mortality.

Work on phthalate esters has been limited to freshwater or anadromous organisms. In an effort to establish LC_{50} values for freshwater organisms, Mayer and Sanders (1973) reported DNBP to be less toxic to rainbow trout (96-hour LC_{50} = 6.5 mg/l) than to the other fish tested. Phthalate esters are metabolized by freshwater fishes (Stalling, et al., 1973) and both DEHP and DNBP are apparently not acutely toxic to freshwater invertebrates. Sanders, et al. (1973) reported that although invertebrates rapidly accumulate these compounds, their 96-hour TL_{50} (2.1 $-$ > 32 mg/l) is appreciably greater than DDT, by comparison. However, the TL_{50} values for aquatic organisms are 700 to 11,000 times that which inhibited reproduction in one of the invertebrates tested (water fleas).

Synergism and Modifying Effects

No report, however brief, on the effects of synthetic organics on estuarine life would be complete without including the area of synergistic effects and

modifying factors. The term "synergism", unfortunately, has many definitions. For our present needs, we will consider it to mean more than the anticipated additive effects.

This subject has been addressed in depth elsewhere (Livingston, et al., in press) however, a few examples particularly germane to the estuary will follow. Once again, most work in this area has been done in freshwater, however, Lowe, et al. (1971b) reported that oysters exposed to a mixture of 1 mg/l each of DDT, toxaphene and parathion showed reduced growth and histopathological effects. When these mollusks were exposed to the individual pesticides, similar results were not observed.

Eisler (1970) reported on the modifying factors affecting the toxicity of organochlorines and organophosphates to the mummichog, an estuarine fish. The toxicity of organophosphates increased with increasing temperature and salinity and decreasing pH. The toxicity of organochlorines was greatest at intermediate temperatures (20–25°C) and least at an intermediate pH (7–8). Salinity had little effect on organochlorine toxicity.

Nimmo (1973) reported that sublethal levels of the PCB, Aroclor 1254, became lethal to estuarine penaeid shrimp when the test organisms were stressed by reduced salinity. Since this species is migratory and experiences a wide variation in salinity, this finding is particularly significant.

The effect of temperature may be of paramount importance in modifying the toxicity of pesticides to estuarine invertebrates. For example, Koenig, et al. (in preparation) found that blue crabs contaminated with DDT did not die in a field experiment until a cold front caused significant reductions in water temperature.

Effects of Synthetic Organics at the Estuarine Ecosystem Level

With all due deference to the title of this report, pitifully little research has been addressed to the ecosystem level. Although a variable amount of effort has gone into testing the effects of particular toxicants under field conditions (see Appendix C), this is still not approaching the problem on the ecosystem level.

Odum and others have developed metnods for simulating ecosystem energy and material flow on analog computers, but this approach is still twice-removed from reality. On the other hand, such models often indicate what types of information are lacking and also have the advantage that the effects of even extreme manipulations can be tested through many generations or seasonal cycles without any damage to the real world.

Even at the community level, little has been done with respect to the effects of synthetic organics. A variety of community parameters have been suggested as reflectors of a community's health. Margalef's "species richness" and Peilou's "species diversity and evenness" are but a few. Researchers are only now finding out that many of these parameters are not the panaceas they thought they were. The main problem lies with trying to use these techniques out of the context for which they were originally intended.

If it is possible to consistently and accurately describe some ecosystem parameter, then it ought to be theoretically possible to quantitate a change in that parameter. The absence of this kind of effort in the estuarine and other habitats is merely a reflection of our current inability to describe such changes, not evidence of its non-existence.

RECOMMENDED RESEARCH

It goes without saying that there are existing programs that have to continue. One such program is the National Pesticide Monitoring Program. It is also imperative that we have an established framework, like the one at the Gulf Breeze Laboratory, whereby chemicals which come under public scrutiny, can be quickly tested.

As an overview, emphasis in future research should be given to determining the significance of the residues being reported in the literature. This can be accomplished by stressing the diagnostic aspects of experimentation during the planning stage and encouraging toxicological studies that have direct relevance to the real world.

In this light, the area of field-testing toxicants has progressed in a manner that reflects individual idiosynerasies and the idiomatic characteristics of the funding and/or research organization (Appendix C). Efforts should be made to, at least, roughly standardize field-testing techniques with a keen awareness of the possible modifying and synergistic effects that one will encounter in the estuary. Interpretation of field exposures will require coordinated efforts in the laboratory under less real, but more controlled, conditions. It is only there that statistically and logistically complicated designs can reach fruition and elucidate specific modes of action, synergy, latent effects, food-chain magnification, and so forth.

On the gobal scene, interdisciplinary efforts should be made to more thoroughly characterize the ki-

netics, marketing patterns, and use of widespread synthetic organic compounds, like phthalate esters, other plasticizers, chlorinated dibenzofurans, and dioxins and HCB. We need to know more about their environmental kinetics, especially their metabolism in soil and water.

As to specific chemicals that need experimental attention, PAE's, HCB, dioxins and dibenzofurans are high on the list.

PAE's are widespread in freshwater fish with higher residues appearing to be associated with industrial areas (Stalling, et al., 1973). They have been shown to be more toxic to aquatic organisms than warm-blooded animals. These esters disturb reproduction and growth in aquatic invertebrates and fish yet nothing is known about their effects on estuarine species.

Although not widely reported in the literature, HCB has been found in environmental samples (Holden, 1970). In view of the possible analytical confusion with benzene hexachloride (BHC), HCB may be even more widespread. With this potential and the documented toxicity of this compound to birds in mind (Vos, et al., 1968), the effects of HCB on fish-eating birds is of concern.

Initial work with the dioxin TCDD indicates important effects on the growth and reproduction of anadromous and freshwater species (Miller, et al., 1973). Again, nothing is known about the effects on estuarine species.

Dibenzofurans were not particularly lethal to the trout they were tested on (Zitko, et al., 1973), however, nothing is known about their sublethal effects. In addition, because of different osmoregulatory mechanisms, the effects on euryhaline species may be considerably different.

As to the level of emphasis and the parameters that need attention, efforts should be made to characterize effects at the ecosystem and/or community level. This is the final biological-physical-chemical integration that will reflect individual perturbations at any sublevel if, in fact, they are significant. As a prelude to this, more intensive research is necessary on the sublethal effects, with special emphasis on behavior and biochemistry. In terms of the experimental design of laboratory studies, more attention should be given to synergistic effects and latent responses. With reference to the former, research aimed to elucidating the modifying effects of sewage and storm runoff is long overdue.

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APPENDIX A

Synthetic Organic Residues Found in Estuarine Organisms

Taxa	Pesticides	Industrial Toxicants	Comments	Reference
PISCES				
Fish	DDT, DDE, DDD		Shows "biological magnification"	Woodwell, et al., 1967
Fish Britain	DDT, DDE, DDD, BHC, heptachlor		Residues vary with species	Moore & Tatton, 1965
Seatrout eggs	DDT		Causes spawning failure	Butler, 1969
Fish and fish oil	DDE, DDD	PCB's	Residue greater in industrialized coastal area	Jensen, et al., 1969
Fish in estuary		Aroclor 1254	Appears to have no effect on juvenile stage—(pinfish)	Duke, et al., 1970
Fish	DDT		Residues up to 16 ug/g	Butler, 1968
Pacific fish	DDT		Highest concentration in coastal fish	Risebrough, et al., 1967
Fish	DDT		Mortality following tidal ditch spray	Croker & Wilson, 1965
Pacific fish-livers	BHC, heptachlor, aldrin, toxaphene, chlordane, methoxychlor, dieldrin, endrin, DDE, DDD, DDT		Bottom dwellers contain higher concentration than pelagic	Duke & Wilson, 1971
Atlantic fish	DDE, DDT, DDD, hexachlorobenzene	Aroclor 1242, 1254, 1260	Higher concentration in surface swimmers	Zitko, 1971
Fish estuarine	DDT		Fatal to predators at different trophic levels	Butler, 1966c
Atlantic fish		Phenoclor DP6	Lower chlorinated PCB's more frequent in fish than birds	Koeman, et al., 1969
Processed and unprocessed Canadian fish		Phthalates	Low levels were found in 21 samples of fish available to the Canadian consumer	Williams, 1973
Many species	DDE	PCB's	Compilation of residue data	Zitko & Choi, 1971
Many species		Aroclor 1254	Geographic comparisons	Risebrough & de Lappe, 1972
Groupers; Gulf of Mexico and Bahamas	DDE, DDT	Aroclor 1260	Geographic comparisons	Giam, et al., 1974
Fish		HCB	Reported 0.002 ppm (salmon eggs)—0.11 ppm (menhaden oil)	Johnson, et al., 1974
MAMMALIA				
Dolphin	DDT		Concentrated in blubber	Butler, 1966c
Dolphin and seal	dieldrin, DDT, DDE, TDE		Largest amounts in blubber	Holden & Marsden, 1967
Seals	DDE, DDD	PCB	Level consistent throughout all parts of body	Jensen, et al., 1969
AVES				
Bald eagle	DDT, DDD		Caused death?	Reichel, et al., 1969a
Seabirds; North Atlantic	DDT	Aroclor 1254	Present in nonmigrating Arctic birds	Bourne & Bogan, 1972
Seabirds and their predators	DDT	PCB	Data on DDT/PCB ratios	Risebrough, et al., 1968b
Bald eagle and eggs	DDE, dieldrin	PCB	From many areas around North America	Wiemeyer, et al., 1972
Bald eagle and golden eagle	DDE, DDD, dieldrin, DCBP, endrin, heptachlor		Higher levels in bald eagles	Reichel, et al., 1969b
Terns	DDT, DDE	Aroclor 1254	Deformities in young	Hays and Risebrough, 1972
Sea birds (Britain)	DDT, HEOD		Seasonal variation	Robinson, et al., 1967
Sea birds and eggs	DDE, dieldrin	Aroclor 1254	Highest residues in freshwater fish-feeding birds	Prestt, et al., 1970

Taxa	Pesticides	Industrial Toxicants	Comments	Reference
Brown pelican eggs	DDT	PCB	Eggshells thin	Schreiber & Risebrough, 1972
British sea birds	DDE	PCB	More PCB's than organochlorines	Holmes, et al., 1967
Sandwich tern	telodrin, dieldrin, endrin, DDE	Phenoclor DP5	Population decline due to pesticides	Koeman, et al., 1967
Birds and eggs		Phenoclor DP6	Some parts of mixture metabolized	Koeman, et al., 1969
Brown pelicans, petrels and shearwaters		Aroclor 1254	Geographic comparisons	Risebrough & de Lappe, 1972
Cormorant and gull	DDE, DDT	Aroclor 1254	No dioxins nor benzofurans found in eggs and tissue	Zitko, et al., 1972
Gull eggs	DDE	PCB's	Hexachloronaphthalene present but no dioxins nor benzofurans found	Bowes, et al., 1973
Eggs of Florida fish-eating birds	DDE, dieldrin	Aroclor 1254	2–20 ppm (OD) DDE; 1–161 ppm PCB	Lincer & Salkind (sic), 1973
Brain and eggs of endangered petrel	DDE		0.23–0.38 ppm (OD) in eggs	King & Lincer, 1973
Bald eagles		Aroclor 1254	Confirmation by mass spectrometry	Bagley, et al., 1970
Many species of fish-eating birds	DDE	PCB's	Compilation of residue data	Zitko & Choi, 1971
Shorebirds and fish-eating birds	DDE	PCB's	Compilation of residue data and comparison of DDE residues to eggshell thickness	Keith & Gruchy, 1972
Heron egg, Britain		PCB	Application of mass spectrometry	Richardson, et al., 1971
British seabird eggs	dieldrin, DDE, DDT, BHC, heptachlor		Higher levels in eggs of larger birds	Moore & Tatton, 1965
Sea birds	DDT, DDE, DDD		"Biological magnification"	Woodwell, et al., 1967
Pacific sea birds	DDT, DDE, DDD		Residue levels higher in California birds than northern migrants	Risebrough, et al., 1967
Swedish sea birds	DDE, DDD	PCB	"Biological magnification"	Jensen, et al., 1969
Birds and eggs, Long Island, N.Y.	DDT and its metabolites, dieldrin		Residues in eggs of fish-eating birds	Foehrenbach, 1972
MOLLUSCA				
Mollusks, Britain	dieldrin, DDT, DDE, DDD, heptachlor, BHC		Traces present in all mollusks tested	Moore & Tatton, 1965
Oysters	DDT		Rate of shell growth indicator of pollution level	Butler, 1969
Mussels	DDE, DDD	PCB's	Lower average concentration in less industrialized area	Jensen, et al., 1969
Oysters		Aroclor 1254	Shell growth of juvenile completely inhibited upon exposure	Duke, et al., 1970
Oysters	DDT		A good monitoring organism	Butler, 1968
Mussels	DDT	PCB		Koeman, et al., 1969
Oysters, clams, mussels, snails	DDT, DDE, DDD, dieldrin		Amounts varied with proximal land use	Foehrenbach, 1972
PLANKTON				
Phytoplankton	DDT, DDD, DDE		Concentrations tripled 1955–1969	Cox, 1970
Zooplankton	DDT, DDE, DDD		Low residues shown for low trophic level	Woodwell, et al., 1967
CRUSTACEA				
Sandcrab	DDT, DDE, DDD		Concentrations due not only to agriculture usage but industrial waste discharge (DDT plant)	Burnett, 1971
Crayfish and shrimp		Aroclor 1254	Concentrate rapidly to equilibrium	Sanders & Chandler, 1972

Taxa	Pesticides	Industrial Toxicants	Comments	Reference
Shrimp	DDT, DDE, DDD		Sensitivity correlated to substantial reduction in population	Woodwell, et al., 1967
Shrimp, crabs		Aroclor 1254	Higher concentration than oysters	Duke, et al., 1970
Fiddler crabs	DDT, DDE, DDD, dieldrin		Residue levels in Uca	Foehrenbach, 1972
MISCELLANEOUS				
Aquatic insect larvae		Aroclor 1254	Failed to metamorphose to adult stage	Sanders & Chandler, 1972
Sea urchin, snail	DDT compounds		All insecticide in gonads of sea urchin	Risebrough, et al., 1967
Water & sediment		Aroclor 1254	A gradient with distance from pollution source	Duke, et al., 1970
Suspended organic matter; San Francisco Bay		Phthalate esters	Utilization of mass spectrometry methods	Simoneit, et al., 1973
Crown of thorns; Pacific		PCB (similar to 1254)	Estimated levels of 0.01–0.05 ppm	McCloskey & Doubert, 1973
Green sea turtle eggs; South Atlantic	DDE	1242, 1248, 1254	0.24–1.81 ppm PCB (lipid basis); ND–0.08 ppm DDE	Thompson, et al., 1974
River water; New England		Phthalate	Reported 0.9–1.9 ppb	Hites, 1973

APPENDIX B

Effects of Synthetic Organic Compounds on Estuarine Organisms

Treatment	Taxa	Organochlorine Insecticides	
		Observed Effects	Reference
Seven pesticides; .1 to 5 ppb; 5 year monitoring	clams oysters	Different species take up pesticides at specific rates. Sublethal long range effects more significant than acute toxicity.	Butler, 1971
Endrin, aldrin, heptachlor	oysters	Linear relation between concentration and shell growth.	Butler, 1965
Dieldrin, kepone	oysters	Sharp threshold of toxicity relative to shell growth.	
DDT, 1 ppb	clam	No effects for 3 months. 30% mortality 4th month.	
DDT-toxaphene, parathion—together and separately, <3.0 ppb	oysters	10% less body weight. Tissue changes, loss of resistance to parasite.	Lowe, et al., 1971b
12 pesticides ranging from lindane, 9.10 ppm to CoRal 0.11 ppm	oyster eggs & larvae	50% of eggs develop normally at given concentrations.	Davis & Hidu, 1969
12 pesticides ranging from lindane & aldrin <10 ppm, to N3514, <1.0 ppm	clam eggs	Same as above.	
DDT >1 ppm <1 ppm	oyster	Remain closed or show spasmodic shell movements at higher levels; decrease in shell deposition at lower levels.	Butler, 1966a
DDT in oil spray, .2–1.6 lb/A	isopods amphipods prawns	High mortality. High mortality. High mortality.	Springer, 1961
0.3 to 0.8 lb/A	blue crab	10–100% mortality.	
Repeated applications	spiders crabs insects marsh crabs red mites fish molluscs snails turtles frogs mammals	High mortality. High mortality. High mortality. Resistant. Not affected. Some deaths. Not affected. Not affected. Not affected. Not affected. Not affected.	
Aldrin 0.2 lb/A	insects prawns crabs fish	More affected than by DDT. Less affected than by DDT. Less affected than by DDT. Less affected than by DDT.	Springer, 1951
Gamma BHC 0.2 lb/A	crabs	Most toxic insecticide tested.	
DDT—2 ppm fed	fish shrimp	50% mortality. DDT in dead laboratory animals less than in seemingly healthy ones in field.	Butler, 1966c
DDT 1–500 ppb	phytoplankton	Photosynthesis reduced.	Wurster, 1968
DDT 0.2 lb/A	fish crabs	Some mortality among animals that could not avoid pesticides.	
Strobane 0.3 lb/A	3 species crabs	Same as DDT.	
BHC 0.1 lb/A	fiddler crabs	Fiddler crabs lost ability to escape predators.	George, et al., 1957
DDT in oil spray, .3 to 16 lb/A	snakes amphibians lizards turtles	High mortality following symptoms of poisoning.	Herald, 1949
Dieldrin, .0006 to .012 ppm	sailfin molly	Killed by 72 hours. Raised serum glutamic oxaloacetic transaminase to 1500 to 1700 units.	Lane & Scura, 1970

Treatment	Taxa	Organochlorine Insecticides	
		Observed Effects	Reference
.003 ppm		Survived to 120 hours. Raised SGOT to 6006-11,954 units.	
Dieldrin .012 to .003 ppm .0015 and .0075 ppm	sailfin molly	100% mortality 1st to 31st week. More than half survived to week 34; growth and reproduction adversely affected.	Lane & Livingston, 1970
Aldrin & dieldrin	fiddler crab trout crayfish tissues	Selectively inhibited cholinesterase activity in homogenized tissues. Cholinesterase very sensitive to small amounts of pesticide.	Guilbault, et al., 1972
DDT 1.0 ppb/2 wks 0.1 ppb/5 wks	fish	Maximum concentration reached at 2 weeks. 38,000 x test water conc. Loss of 78–87% in 8 weeks.	Hansen & Wilson, 1970
DDT, endrin 0.1 to .00001 ppm	minnows	Avoided water containing pesticides. Did not distinguish concentration differences.	Hansen, 1969
DDT 50 ppm	eel intestine	Inhibition of water absorption. Inhibition of (Na^+ and K^+) activated Mg^{2+}-dependent adenosine triphosphatase.	Janicki & Kinter, 1971
Mirex, 1–5 particles of bait in standing sea water or Mirex in flowing sea water 1.0 to 0.1 ppb	juvenile shrimp juvenile shrimp juvenile blue crab fiddler crabs fish	40 to 100% mortality Up to 100% mortality delayed until shrimp in Mirex free water. Up to 96% mortality, delayed. Accumulated Mirex in bodies. Accumulated Mirex in bodies. Gill parasites reduced.	Lowe, et al., 1971a
DDT 2–5 μg/g	shrimp crab fish pinfish	35–100% mortality. Accumulated DDT in bodies.	Butler, 1968
DDT <1 ppm	oyster	Feeding & shell growth stopped. Erratic shell movements.	Butler, 1967
DDT 2–4 ppm on food	fish shrimp	50% mortality in 2–4 weeks.	
DDT in flowing sea water 0.1 ppm 0.05 ppm	shrimp shrimp	Lowered Na^+ and K^+ in hepatopancreas, change in Na^+ and K^+ only after day 20.	Nimmo & Blackman, 1972
DDT in flowing sea water 10 ppb	juvenile shrimp	100% mortality.	Nimmo, et al., 1971b
DDT 0.05 to 0.17 ppb 0.12 to 0.20 ppb	shrimp	DDT concentrates in hepatopancreas. Flushed from hepatopancreas within 6 weeks. 100% mortality 18 to 28 days.	Nimmo, et al., 1970
Mirex .001, .1, 1.0 & 10 ppb	crab larvae	Larval stages prolonged. Increased mortality.	Bookhout, et al., 1971
DDT 10 ppm on detritus	fiddler crabs	100% lost coordination by day 5. Three-fold accumulation in claw muscles.	Odum, et al., 1969
Toxaphene	fish shrimp, crabs	Established 96 hour TL_m values; includes data on synergy and histopathology.	Courtenay & Roberts, 1973
DDE	duck	Eggshell thinning complete after 4 days on 40 ppm diet; electron microscopy.	Peakall, et al., 1973
DDE, dieldrin	duck	20 ppm DDT or 10 ppm dietary doses resulted in eggshell thinning.	Davison & Sell, 1974
DDT group, dieldrin, heptachlor, toxaphene	duck	Established effects on eggshell thinning.	Haegele & Tucker, 1974
DDE	duck	LC_{50} values varied with age of ducks (1200–1600 ppm).	Friend & Trainer, 1974
Dieldrin; .1–50 ppm	fiddler crabs	Levels correlated with maladaptive behavior and mortality. Latent effects.	Klein & Lincer, 1973

Treatment	Taxa	Organophosphate Insecticides	
		Observed Effects	Reference
Parathion	oysters	Sharp threshold of toxicity relative to shell growth.	Butler, 1965
4 pesticides ranging from guthion .62 ppm, to TEPP 10.	oyster eggs clam eggs	50% of eggs develop normally.	Davis & Hidu 1969
Malathion, dursban; 10–.01 ppm	minnows	Did not avoid Malathion. Did avoid Dursban.	Hansen, 1969

Treatment	Taxa	Organophosphate Insecticides: Observed Effects	Reference
Paraoxon, DDVP parathion, methyl parathion	fiddler crabs trout crayfish tissues	Selectively inhibited cholinesterase activity in homogenized tissues. Cholinesterase sensitive to small amounts of pesticide.	Guilbault, et al., 1972
Malathion, naled, guthion and parathion	fishes and pink shrimp	Revealed comparative AChE inhibition.	Coppage & Matthews, 1974
Parathion	duck	Established effect on eggshell thinning.	Haegele & Tucker, 1974

Treatment	Taxa	Carbamate Insecticides: Observed Effects	Reference
Sevin 0.1 ppm	juvenile fish	Survived normally, neural parasite may not be related to toxicant.	Lowe, 1967
Sevin 0.01–10 ppm	minnows	Did not avoid Sevin.	Hansen, 1969
Sevin	gastropod (oyster drill)	Swelling at 6–7 hours exposure.	Wood & Roberts, 1963
Matacil, mesurol, zectran, baygon, sevin	fiddler crabs crayfish trout	Selectively inhibited cholinesterase activity in homogenized tissues. Cholinesterase very sensitive to small amounts of pesticides.	Guilbault, et al., 1972

Treatment	Taxa	Herbicides, Bacteriocides, etc.: Observed Effects	Reference
12 herbicides ranging from amitrol 733.70 ppm to silvex 2.4 ppm nemagon, sevin	oyster eggs clam eggs	50% developed normally.	Davis & Hidu, 1969
19 bacteriocides, algicides, fungicides from untinted sulmet 1000 ppm to phygon .014 ppm	oyster eggs clam eggs	50% developed normally.	
2,4-D acid	duck	Established effect on eggshell thinning.	Haegele & Tucker, 1974
4 herbicides in sea water	6 genera algae	Carbohydrate concentration depressed. Varies with salinity.	Walsh & Grow, 1971
Nitrilotriacetic acid	phytoplankton	Low toxicity as long as chelate:metal ratio favorable; NTA alone, trace metal deficiency.	Erikson, et al., 1970
2,4-D, 0.01–10 ppm	minnows	Avoidance of herbicide.	Hansen, 1969
Antimycin A 7 ppb	38 species fish other fish oysters plankton crabs	Killed in three days. No effect.	Finucane, 1969
Polystream (chlorinated benzenes)	oyster drill	Under recommended dosage, 50% of animals killed by day 7.	Wood & Roberts, 1963

Treatment	Taxa	Industrial Toxicants: Observed Effects	Reference
Aroclor 1254 .94–100 ppb	juvenile shrimp	51 to 100% mortality.	Nimmo, et al., 1971b
Aroclor 1254 2.5–3.5 ppb	adult shrimp	50% mortality, accumulated in hepatopancreas. 23% died after return to sea water.	
Aroclor 1254 in Corexit 7664 colloidal solution emulsions	Gammarus Gammarus	Lethal threshold 0.001 to 0.01 ppm. Lethal threshold .01 to .1 ppm.	Wildish, 1970
Aroclor 1254 1 ppb to 56 days 5 ppb 14–45 days	fish	No apparent effect at 1 ppb; Mortality occurred, though delayed at 5 ppb.	Hansen, et al., 1971
Aroclor 1254 100 ppb 48 hours	shrimp oysters pinfish	100% mortality. Shell growth inhibited. Concentrated PCB.	Duke, et al., 1970
5 ppb 20 days	shrimp crabs	72% mortality after day 10. Concentrated PCB.	

Treatment	Taxa	Industrial Toxicants	
		Observed Effects	Reference
Aroclor 1242 and Aroclor 1254 + radiocarbon	phytoplankton	Radiocarbon uptake reduced at as low as 1–2 ppb.	Moore Harriss, 1972
Aroclor 1242 in water .01 to .1 ppm	marine diatom	Inhibited growth, RNA synthesis and chlorophyl index.	Kiel, et al., 1971
Aroclor 1254 in sediment 61.0 ppm (dry wt.) to 1.4 ppm for 30 days	shrimp crabs	Amount of PCB residue in animal varies with amount in substrate.	Nimmo, et al., 1971a
Aroclor 1221; 7.5–75 ppm	killifish	Decreased ability to osmoregulate.	Kinter, et al., 1972
Aroclor 1254	shrimp	60% died at 9.1 ppb (7 day exposure); no significant mortality at 0.62 ppb.	Nimmo, et al., 1974
Aroclor 1254; 0.001–10 ppm	shrimp fishes	Demonstrated that some animals could avoid Aroclor 1254 under laboratory conditions.	Hansen, et al., 1974a
Aroclor 1016	oyster shrimp fish	Established acute 96 hour LC_{50}'s.	Hansen, et al., 1974b
Aroclor 1254	oyster	5 ppb for 24 weeks reduced growth and produced tissue atrophy and degeneration.	Lowe, et al., 1972
Aroclor 1254	duck	Showed PCB influence on susceptibility of birds to virus.	Friend Trainer, 1970
Aroclor 1232, 1242, 1248, 1254, 1260, 1262	duck	Toxicity positively correlated with percent chlorine.	Heath, et al., 1972
Aroclor 1254	duck	Established effect on eggshell thinning.	Haegele & Tucker, 1974
Dioxin (TCDD) in water and food	salmonids	Marked decrease in growth; latent effect.	Miller, et al., 1973
Dibenzofurans	salmonids	Dietary doses up to 122 mg/kg resulted in no mortality.	Zitko, et al., 1973
Phthalate ester	rainbow trout	LC_{50} (96 hour) = 6.47 ppm.	Mayer & Sanders, 1973

APPENDIX C

An Overview of the Field-Testing of Pesticides

Ecosystem	Pesticide	Observed Parameters	Taxa	Reference
F/W Pond	DDT	Mortality	Fish Plankton Benthic Inverts. Reptiles Birds Mammals Terr. Insects	Tarzwell, 1948
Enclosed area of F/W Pond	DDT	Population	Fish	Tarzwell, 1948
Tidal Marsh	DDT	Mortality Gross behavior Growth (snails)	Fish Crabs Shrimp Insects Mollusks Amphipods Worms Mites Birds	Springer and Webster, 1951
Tidal Marsh	Strobane, DDT & HCB	Mortality Gross behavior on fiddlers	Fish Crabs Birds Mammals	George et al., 1957
Tidal Marsh Ditch	Dieldrin	Mortality	Fish Crabs	Harrington & Bidlingmayer, 1958
Tidal Marsh	DDT, aldrin, dieldrin & BHC	Mortality	Fish Prawns Anthropods Iso- and Amphipods Crabs Worms Mollusks Birds	Springer, 1961
Tidal Marsh Ditch	DDT	Mortality & population; Residue monitoring	Fish Crabs	Croker & Wilson, 1965
Estuaries	2,4-D	Mortality	Fish Crab Oysters Clam	Rawls, 1965
Salt Marsh F/W Pond	Dursban	Mortality	Fish Shrimp Crabs Oyster Insects Terr. Verts.	U.S.D.I., 1967a
Mangrove Swamp	Dibrom	Mortality Cholinesterase Population	Fish Crab Mammals Birds Insects	U.S.D.I., 1967b
Salt Marsh	Dursban	Mortality Monitoring	Fish Crab Shrimp Birds	Ludwig, et al., 1968
Tidal Marsh	Dursban	Mortality Cholinesterase inhibition	Fish Crabs Shrimp Mammal Bird	U.S.D.I., 1968
Salt Marsh	Malathion	Mortality Cholinesterase	Fish Crab Shrimp Mollusks	Tagatz, et al., 1974

TRACE METALS IN THE OCEANS: PROBLEM OR NO?

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ABSTRACT

Increased input of mercury to the estuarine environment resulted in bioaccumulation in marine food chains that affected man (Irukayama, 1966). Toxic effects of other metals on marine animals has been demonstrated under laboratory conditions. However, cause and effect between elevated environmental metals levels and toxicity to marine animals has yet to be conclusively demonstrated under field conditions. Municipal waste water treatment plants, dredging and spoiling activities, and the dumping of sewage sludge and industrial wastes are the major sources of metals to the marine environment. These sources are likely to increase in the future unless the Federal Water Pollution Control Act Amendments of 1972 (PL-92-500) are carefully enforced.

INTRODUCTION

Estuaries, because they are landward extensions of the sea, have become centers of industrial, commercial, and related activities. As a consequence, estuaries have received an increasing input of metals, the byproducts of modern industry and technological advancement. Metals can be introduced indirectly from contaminated rivers and land runoff or directly by pumping from land based industries and municipalities, ship and barge discharges, and aerial fallout (Merlini, 1971). When viewed as a whole, ocean systems appear to be beyond compromise in their ability to dilute introductions from man's activities—after all, the continental masses are continually bathed in their oceans and seas. Where then do problems occur?

Ocean waters, especially estuaries, are not uniformly mixed and non-uniform dilution can cause local concentrations of metals. Metals tend to be concentrated at air-sea, sediment-water, or freshwater-saltwater interfaces and boundaries between water and living or dead particles (Fig. 1). Some metals discharged even in small quantities can be accumulated to alarming and lethal levels by certain marine biota. Seafoods harvested by man can become extensively impacted when excessive metals are added to the sea. A classic example of the human aspect of this problem first received widespread attention when mercury poisoning occurred in Japan in 1953 through consumption of contaminated fish and shellfish (Irukayama, 1966).

Sediments in estuaries naturally tend to have relatively high levels of metals. As long as the biological component of estuarine benthic systems (bottom related systems, including sediments, plants, and animals living on or in them) is alive and well, the naturally enriched sediments appear to be processed and metals are biologically recycled into the system. However, frequently these benthic systems are stressed beyond the biological breaking point, and the biota is eliminated or drastically reduced. If the biological recycling system is destroyed, an anaerobic sedimentary system develops, and among other things, becomes a metals sink. The elements that were formerly recycled accumulate to orders of magnitude above those observed in biologically active systems. There is a "leaching out" of these metals, but the rates now controlled primarily by physical-chemical processes go on at a very slow pace.

Two problems emerge when sediments become sinks rather than recyclers for metals.

1) Due to relatively rapid sedimentation that occurs in upper estuarine areas, channels must be dredged. Very frequently, dredged materials are anaerobic and rich in elemental composition. Where can they be dumped with assurance that those materials which enrich the sediment may not prove noxious to man directly or indirectly through reduction in marine resources?

2) If an estuary which receives feedback from its sediments in the form of nutrients—both organic and inorganic—loses a part of this benthic recycling activity, what are the long-term and short-term effects? For example, does the creation of a metal sink in estuarine sediments affect plankton productivity and species composition?

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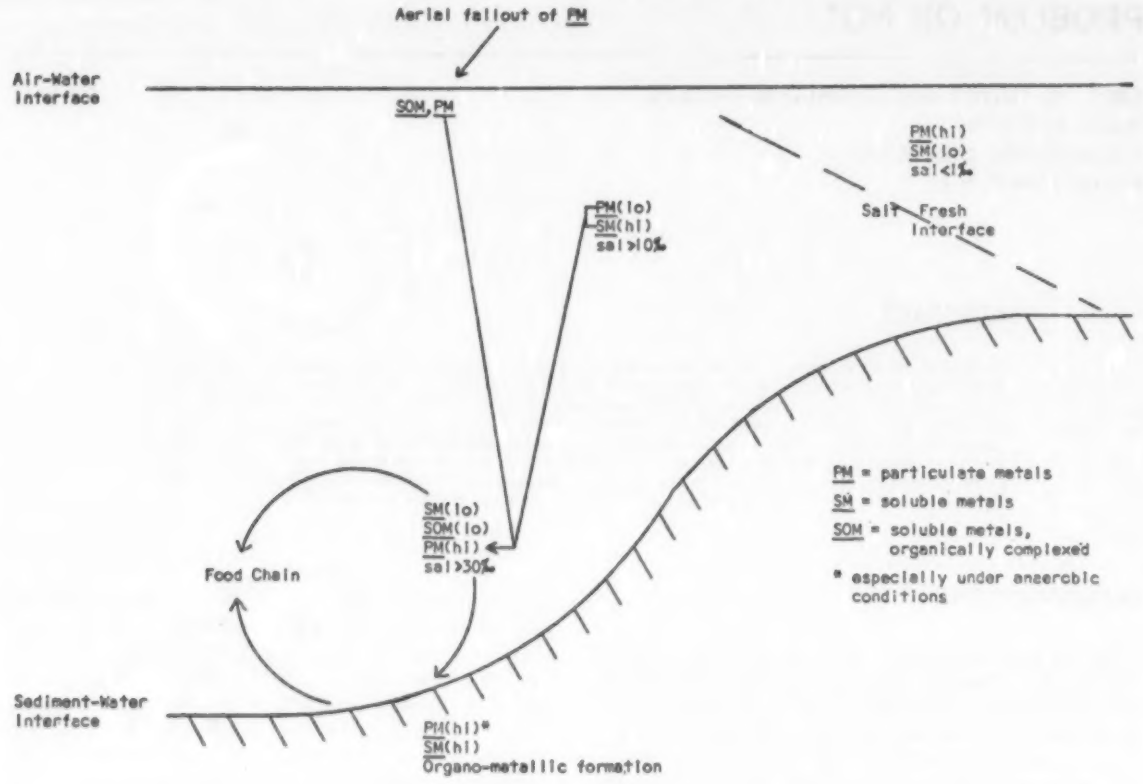

FIGURE 1.—Generalized diagram for sites of metal concentration and transformation of metal forms in the marine environment.

The possible problems of metals in estuaries is emphasized to illustrate the complexities that surround this problem area. Some aspects of the metal problem are of more direct concern to the welfare of man and estuarine systems than others. In an effort to prioritize and define metal problems in the marine environment a metal matrix has been created.

METHODS AND MATERIALS

Trace elements are essential to all life systems, yet excess amounts are toxic. Also, non-essential elements such as mercury, cadmium, lead, and so forth can be toxicants and bioaccumulated to large quantities to affect organisms within marine food chains, including man. Therefore, a matrix of existing toxicity and body burden data using marine species as one axis and metals as the other has been formulated in order to assess, broaden, and validate the data base needed to establish criteria. The metals matrix helps to point out information gaps, thereby defining research goals; it also provides a basis for comparing metal levels and their modes of application in laboratory studies with levels and pathways defined in the natural environment.

A summary of two metals matrices which were constructed mainly from literature reviews by Ketchum, et al., (1972), and Eisler (1973), more recent additions from the open literature, and in-house experiments performed at the National Marine Water Quality Laboratory (NMWQL) are presented in Tables 1 and 2.

RESULTS

The metals matrix indicates that we have information on only 36 elements and of these only 18 have toxicity data listed and of the 18 perhaps only four (Cd, Cu, Hg, and Zn) are sufficiently documented to formulate good criteria. Since the NMWQL has had to respond to unexpected requests for elemental toxicity and bioaccumulation data, in order to anticipate future requests, we have undertaken an in-house program to develop acute and chronic marine bioassay information on a wide spectrum of elements.

However, because combinations of marine biota

Table 1.—Matrix of elements versus marine biota response

Element	Environmental Oceans Clean	Spp. (Phyla) Tested	Organism	Most Sensitive Level	Response
Aluminum	0.01	4 (3)	Redfish	88*	Death
Antimony	0.0005	2 (2)	Algae	3.5	Inhib. cell div.
Arsenic	0.003	6 (4)	Copepod	0.1	72hr LC_{50}
Beryllium	0.0000006	1 (1)	Mummichog	0.0001	Decr. enz. act.
Cadmium	0.0001	34 (7)	Oyster	0.015	Slow sex. devel.
Chromium	0.000005	13 (5)	Algae	0.0001	Decr. culture yield
Cobalt	0.0001	1 (1)	Copepod	0.01	72hr LC_{50}
Copper	0.003	48 (9)	Diatom	0.001	Inhib. growth
Germanium	0.00006	2 (1)	Diatom	1.0	Inhib. growth
Gold	0.000004	1 (1)	Piafish	0.069	Death
Iron	0.0013	1 (1)	Diatom	0.027	Cell clumping
Lead	0.00003	14 (7)	Ciliate	0.15	Inhib. growth
Manganese	0.005	2 (2)	Oyster	16.0	LC_{50} of embryos
Mercury	0.00003	43 (8)	Oyster	0.0056	48hr LC_{50} of embryos
Nickel	0.002	17 (4)	Algae	0.0002	Inhib. growth
Selenium	0.0004	5 (2)	Copepod	0.01	96hr LC_{50}
Silver	0.00004	9 (5)	Copepod	0.0033	72hr LC_{50}
Yttrium	0.003	1 (1)	Oyster	0.001	Abnormal larvae (90%)
Zinc	0.01	28 (8)	Annelid	0.05	Abnormal larvae

* All concentrations expressed in mg/kg.

Table 2.—Matrix of elements versus marine biota bioaccumulation

Element	Spp. (Phyla) Tested	Organism	Level Reached	Toxic to Man
Aluminum	7 (1)	Phytoplankton	5000*	–
Antimony	42 (10)	Octopus	0.92	+
Arsenic	88 (12)	Squid (gills)	198	+
Barium	3 (1)	Phytoplankton	262	–
Beryllium	1 (1)	Phytoplankton	8.4	+
Bismuth	1 (1)	Phytoplankton	7.7	+
Cadmium	136 (12)	Abalone (digest. gland)	1162.7	+
Cerium	16 (5)	Fish	64	–
Cesium	20 (6)	Algae	0.64	–
Chromium	30 (4)	Zooplankton	260	+
Cobalt	34 (7)	Zooplankton	110	–
Copper	101 (8)	Squid (liver)	15,160	–
Gold	3 (1)	Mollusc	282	–
Iron	73 (8)	Annelid	42,800	–
Lanthanum	4 (2)	Fish	57	–
Lead	102 (7)	Algae	3100	+
Manganese	51 (5)	Algae	226	–
Mercury	198 (15)	Algae	7400	+
Molybdenum	5 (3)	Zooplankton	36	–
Nickel	45 (6)	Zooplankton	480	–
Plutonium	38 (7)	Algae	21,000 (CF) #	+
Polonium	1 (1)	Fish	61 pCi/gm wet wt	+
Rubidium	6 (3)	Algae	2.3	–
Ruthenium	11 (7)	Sponge	10,000 (CF)	–
Samarium	15 (3)	Annelid	3.6	–
Scandium	20 (4)	Annelid	26.4	–
Selenium	11 (5)	Octopus	71	+
Silver	18 (4)	Squid (liver)	1044	–
Strontium	18 (5)	Algae	4160	–
Thorium	5 (3)	Octopus	9.2	+
Tin	2 (2)	Phytoplankton	101	–
Titanium	6 (2)	Phytoplankton	940	–
Uranium	1 (1)	Fish	21	+
Vanadium	6 (2)	Pteropod	290	–
Yttrium	2 (2)	Mollusc	1000 uCi	–
Zinc	130 (10)	Mollusc	99,220	–

* All values in mg/kg, except where noted.
# CF—concentration factor.
Toxic to Man: + yes; – no.

versus elemental compounds exist in infinite variety, a number of elements can be eliminated from consideration in the following categories:

1. Elements such as mercury with sufficient information for good water quality criteria.
2. Major constituents of seawater, s.a. Na, Mg, Cl, S04.
3. Major constituents of marine organisms, s.a. C, H, N, O.
4. Noble gases, i.e. He, Ne, et cetera.
5. Elements which are short half-life isotopes.
6. Rare earths.

The remaining, approximately 50 elements, can be listed in priority according to the following considerations:

1. Known toxicity to man.
2. Information indicating elemental impact in the marine environment.
3. The form of the element in seawater.
4. No information available.

It must also be recognized that it is not necessarily the total amount of a metal present in seawater or marine sediments but the form of the metal which may be important to consider with respect to its effects on marine biota. Metals in seawater can be operationally characterized as particulate (metals associated with particles larger than 0.45μ) or dissolved ($< 0.45\mu$). Dissolved metals can be categorized further as inorganically associated, organically bound, i.e. chelated, or metal-organic compounds. Dissolved metal forms are likely to interact with most marine biota; however, the effects may differ if the metals are organically bound. If a metal such as copper is chelated, there may be a reduction in metal toxicity response by organisms such as marine phytoplankton; whereas, if the metal is an organometallic like methyl-mercury, this compound is more toxic than the inorganic form and can also be concentrated in food chains. Particulate metals, probably occurring in high levels near industrial outfalls or ocean dumping activities, are likely to affect filter feeding organisms which ingest and concentrate particulate matter. Consequently, the form of the metals may be the dictating factor in the response of marine biota to heavy metals.

On the basis of these considerations, elements are chosen for short-term, acute bioassays. Acute bioassays involve a rapid response of a single species to increasing concentrations of a toxicant. The results of the acute bioassay are reported as the median tolerance limit (TL_m or TL_{50}) which signifies the concentration of toxicant that kills 50 percent of the organisms within a specified time span, usually in 96 hours. Organisms for acute bioassay are being selected from a wide range of representative marine phylla and growth stages.

Elements having low TL_{50} are in turn chosen for long-term chronic bioassays. Chronic bioassays involve a continuous exposure to a sublethal concentration of the toxicant. In the chronic bioassay, any biological response, such as reduction of growth or reproduction, behavior change, histopathological change, et cetera, can be used to monitor effects. Also, test organisms are analyzed to determine possible bioaccumulation of the element which could in turn indicate a potential pathway back to man.

DISCUSSION

A definite need exists to carefully inventory all natural and manmade element sources which might impact the marine environment. Table 3 is a generalized inventory. Assessing potential ocean pollutants, Robinson, et al., 1974, have presented an extensive and important approach for budgeting pollutants; however, the report deals only with the metals iron, copper, and plutonium and concludes that plutonium is the only element of potential global pollution. Similar assessment should be made for all elements; however, these assessments should be focused at more localized areas, such as coastal or estuarine areas as well as on a global scale. These inventories would highlight elements of major environmental concern which should be carefully bioassayed in the laboratory. Also, these budgets should point out specific areas of high metal impact in the United States.

Field investigations of metal impacted areas throughout the U.S. are necessary in order to determine the extent, fate, and effects of metals on marine biota. Have metals per se directly or indirectly caused environmental damage and, if so, to what extent? What are the inputs, rates, routes, and reservoirs of metals within impacted areas? Special consideration should be given to areas of:

1. Mining activities.
2. Smelters.
3. Industrial outfalls, especially metal plating industries.

Table 3.—Inorganic chemicals to be considered as pollutants of the marine environment.

Element	Natural conc in sea water μg/l	World production metric tons/year (1968)	Routes of entry into the sea	Pollution categories
H (acids)	pH = 8 (alk = 0.0024)	?	D,A	III c
Be	0.001	250	U	IV c ?
Ti	2	1,000,000	A ?	IV b ?
V	2	9,000	A	IV a ?
Cr	0.04	1,500,000	R(U)	IV c ?
Fe	10	480,000,000	D,R	IV c
Cu	1	5,000,000	D,R	IV c
Zn	2	5,000,000	D,R	III c
Cd	0.02	15,000	A,R	II c
Hg	0.1	9,000	A,R	I b
Al	10	8,000,000	D,R	IV c
CN	—	?	D,R	III c
Pb	0.02	3,000,000	A,R	I a
P	—	?	D	IV c
As	2	60,000	D	II c
Sb	0.45	60,000	U	IV c
Bi	0.02	3,800	U	IV c ?
Se	0.45	1,000	U	III c ?
F	1,340	1,800,000	D,R	IV c ?

D dumping, A through atmospheric pollution, R through rivers (runoff) or pipelines, U unknown.

I–IV order of decreasing menace; a worldwide, b regional, c local (coastal, bays, estuaries, single dumping).

Referenced from FAO Fisheries Reports, No. 99 Suppl. 1. Report of the seminar on methods of detection, measurement and monitoring of pollutants in the marine environment: Inorganic chemicals, Panel 3. Dyrssen, D., C. Patterson, J. Ui and G. F. Weichart.

4. Sewage outfalls.
5. Desalinization plants.
6. Offshore ocean disposal areas for industrial wastes, sewage sludge, and dredge spoils.

However, Cross and Duke (1974) have emphasized that it is essential that present efforts be continued and new efforts initiated to determine baseline levels of trace metals in marine organisms and the environmental variables that affect them. These studies should be conducted not only in contaminated environments such as Long Island Sound, New York Bight, and the Southern California Bight, but also in relatively pristine or uncontaminated environments. The concentration of any trace metals can be highly variable both within and between species and influenced by a number of environmental factors. Until we understand the variability that exists in healthy ecosystems, it may be difficult to identify a contaminated ecosystem. Also, because trace metals occur naturally in the marine environment as a result of weathering and volcanic activity, the problem of determining the contribution of anthropogenic additions of trace metals to natural levels in marine organisms is more difficult than with halogenated hydrocarbons or refined petroleum products.

Other questions concerning potential metal pol-

lutants which need to be answered are as follows:

1. Are certain industries, such as power plants, producing excessive metal inputs which should be controlled?

2. Can elemental transformations occur within marine areas to produce more lethal and/or bioaccumulated compounds such as methyl-mercury? If so, which elements are capable of transformation and under what circumstances?

3. Dredge spoils removed from navigational channels are often taken from areas which act as traps for sediments laden with river and estuarine-borne waste. What are the long-term effects of these ocean-dumped dredge materials upon the cleaner shelf areas? How should ocean-dumped materials be handled to lessen environmental impact to disposal areas?

4. Liquid effluents from wastewater treatment plants probably will be a major source of trace metals to estuarine and coastal waters during the next several decades. Efforts should be made to evaluate the impact that these discharges will have on concentrations of trace metals in harvestable marine species that complete a major portion of their life cycle in coastal areas.

According to Schroeder (1973), environmental pollution by toxic metals is a much more serious and insidious problem than is pollution by organic substances such as pesticides, weed killers, sulfur dioxide, oxides of nitrogen, carbon monoxide, and other gross contaminants. Most organic substances are degradable by natural processes; no metal is degradable. Elements in elemental form or as salts remain in the environment until they are leached by rains into rivers and into the sea. Therefore, every effort must be made to slow down the environmental build-up of those elements which are toxic and can cause degenerative diseases.

The solution to problems of metal waste disposal might be expected to be dilution into the vastness of the sea. However, because metals can be concentrated by geological, chemical, and especially biological processes in the sea, the solution to metal disposal problems is not dilution. The solution must be to stop pollution at its source by the development of the proper technology to control and recycle metal wastes. Metal wastes entering the marine environment should be reduced if the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) to minimize environmental pollutants are carefully enforced.

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POLLUTION IN NATION'S ESTUARIES ORIGINATING FROM THE AGRICULTURAL USE OF PESTICIDES

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ABSTRACT

Estuaries are particularly vulnerable to pollution because they are repositories of wastes which do not come from a point source, such as pesticides. Agricultural pesticides enter the estuarine environment by several means: direct application to water; runoff from treated lands; industrial discharges; domestic sewage; atmospheric drift; and accidental spills. The fish kills in the Mississippi River by insecticides are well known and particularly well documented. Monitoring data have been limited primarily to chlorinated hydrocarbons because of their number, wide use, great stability in the environment, and toxicity to certain forms of wildlife and other nontarget organisms. A recent national survey on organochlorine residues in estuarine mollusks reveals that "at no time were residues observed of such a magnitude as to imply damage to mollusks." However, residues were large enough to pose a threat to other elements of the biota through recyling and magnification. The maximum pesticide residues can be correlated with proximity of monitoring stations to agricultural runoff. Long-term, sublethal effects of pesticides in estuaries are difficult to assess at present, as most data on pesticide effects are limited to a few species and concentration that is lethal in short-term tests under laboratory conditions. Pesticide pollution in the estuarine environment can be minimized through the use of alternative pesticides, more effective use of pesticides, removal of pesticides from water, improvement of farm management practices, regulatory control of pesticide use, and a better understanding of the pesticide behavior in the estuarine ecosystem.

INTRODUCTION

The ocean's biological productivity is largely concentrated in the coastal zone, from the rivers seaward to the salt marshes, the bays, and estuaries. Productivity is high here because basic nutrients, the minerals and organic material washed down river from land, feed plants and animals at the base of the marine food chain. By weight, about a thousand times more food is caught or harvested from the coastal zone than from the open sea. To put it another way, most fish and shellfish are caught within sight of land. Some 70 percent of the valuable sport fish depend on estuaries for their survival. Like all wildlife, marine animals establish themselves where conditions for life are most favorable—plenty of food, areas for spawning, and freedom from predators.

Estuaries are particularly vulnerable to pollution for two reasons: (1) their natural populations are in delicate balance and thus are easily upset by pollutants, and (2) they are the repository for most of a river's pollution load as the river meets the estuary, slows down, and releases its wastes.

The most difficult pollution control problem—for estuarine and coastal waters—is posed by wastes which do not come from a point source, such as pesticides from runoff and drifts, and fertilizers spread on fields. They find their way into streams and rivers and eventually the estuaries and oceans in ever larger amounts. Some argue that these pollutants are even more dangerous to estuarine plants and animals (including man) than municipal and industrial wastes.

Synthetic organic pesticides when used properly have been of tremendous benefits to man and his environment, but when misused or carelessly used, they cause considerable harm. Fortunately, the adverse effects have so far been relatively minor in comparison to the beneficial role that pesticides have played, and most likely will continue to play in the production of food as the world's supply of raw agricultural products continues to decline in proportion to increasing population.

During recent years the overall use patterns of pesticides have changed considerably. The risk or hazards of using pesticides have increased with the sharp rise in their consumption by agriculture, households, industry, and government. Today, more than 34,000 products made from one or more of 900

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chemical compounds are currently registered by the U.S. Environmental Protection Agency (EPA) for use in the environment.

Pesticides are poisons; they can present an immediate danger to the user if applied improperly or without sufficient knowledge of their toxic effects. In addition, potential future hazards to human health and other living forms can be created by residues from long-lived pesticides that build up in the food chain.

CURRENT PESTICIDE USE IN THE ENVIRONMENT

Except for 1969 and 1970 when there were slight declines, sales of synthetic organic pesticides in the United States have increased every year since 1963 (Table 1). In 1972, the latest year for which figures are available, production was 1,158 million pounds. The volume of sales that year was 1,022 million pounds, and the value of these sales was $1,092 million. The volume and value of producers' sales were the highest of any year for which records are available.

"Pesticides Review 1973," published by the U.S. Department of Agriculture, provides information on the calculated domestic use at the producers' level for pesticides (Table 2). It is interesting to note that, following a general decline in recent years, DDT in 1972 was up nearly 78 percent over 1971. The sharpest decline in 1972 was made by 2,4,5-T which dropped 64 percent. Use of 2,4-D declined over one-fourth in 1972; however, the use of the aldrin-toxaphene group of pesticides increased by nearly one-fourth that year.

It is predicted that the use of pesticides will continue to increase and the sales value was expected to reach $1.4 billion in 1974 (Figure 1). One reason for this optimism is that acreage devoted to the major field crops accounting for most of the total U.S. pesticide use will be increased by 6 percent that year. The five major crops (corn, cotton, rice, soybeans, and wheat) account for approximately 75 percent of the total pesticide use in the United States. Moreover, with prices of all farm crops at or near all-time highs and yields per acre moving up steadily, farmers will have more money available to spend on pesticides, even after allowing for higher prices. (Chemical Week, v. 114, no. 4, January 23, 1974). Additionally, the demand for farm products is growing rapidly worldwide. Since the farmer is the major supplier of farm products in world trade, he will need more pesticides to meet the growing demand.

Table 1.—Synthetic organic pesticides: Production and sales, United States, 1963-72[1]

Year	Quantity	Change from previous year	Value[2]	Change from previous year
	1,000 pounds	Percent	1,000 dollars	Percent
	Production			
1963	763,477	4.6	444,046	3.9
1964	782,749	2.5	473,815	6.7
1965	877,197	12.1	576,787	21.7
1966	1,013,110	15.5	715,362	24.0
1967	1,049,663	3.6	959,260	34.1
1968	1,192,360	13.6	1,028,469	7.2
1969	1,104,381	−7.4	953,592	−7.3
1970	1,034,075	−6.4	1,058,389	11.0
1971	1,135,717	9.8	1,282,630	21.2
1972[3]	1,157,698	1.9	1,344,832	4.8
	Sales (domestic and export)			
1963	651,471	2.8	369,140	6.6
1964	692,355	6.3	427,111	15.7
1965	763,905	10.3	497,666	16.4
1966	822,256	7.6	583,802	17.4
1967	897,353	9.1	787,043	34.8
1968	959,631	6.9	849,240	7.9
1969	928,663	−3.2	851,166	0.2
1970	880,914	−5.1	870,314	2.2
1971	946,337	7.4	979,083	12.5
1972[3]	1,021,565	8.6	1,091,708	11.5

[1] Includes a small quantity of soil conditioners.
[2] Value of production calculated: unit value x quantity; sales value as reported by the Tariff Commission.
[3] Preliminary.
Tariff Commission, Chemical Division, "Synthetic Organic Chemicals, United States Production and Sales."

Table 2.—Pesticides: Domestic disappearance at the producers' level of selected kinds, United States, 1967-72[1]

Pesticide	1967[2]	1968[2]	1969[3]	1970[3]	1971[3]	1972[3]
	1,000 pounds	1,000 pounds	1,000 pounds	1,000 pounds	1,000 pounds	1,000 pounds
Aldrin-toxaphene group	86,289	38,710	89,721	62,282	85,085	105,980
Calcium arsenate	2,329	1,992	2,117	2,900	2,457	1,751
Copper sulfate	85,274	87,452	98,840	77,344	70,272	72,214
DDT	35,757	28,753	25,756	20,457	13,234	23,546
Lead arsenate	6,152	4,747	7,721	5,860	4,142	5,024
2,4-D	66,955	68,404	49,526	46,942	32,174	23,179
2,4,5-T	15,381	15,804	3,218	4,871	1,389	498

[1] Disappearance for all domestic uses, including all nonagricultural and chemical intermediate uses. Includes any exports by firms other than producers.
[2] Includes military shipments abroad; these are not considered exports.
[3] Year ending September 30.
[4] Year ending December 31.
Calculated from data supplied by the chemical industry, Tariff Commission, and Bureau of Mines.

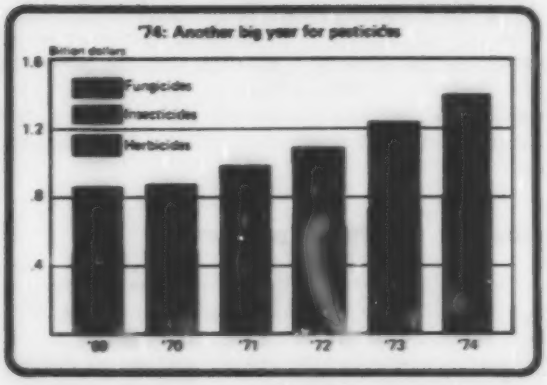

FIGURE 1.—Pesticide sales, 1969–1974. Source: Chemical Week. v. 114, no. 4. January 1974.

Obviously, as the production and use of pesticides continue to increase, the potential for environmental contamination becomes more prevalent.

ROUTES OF PESTICIDE ENTRY INTO THE AQUATIC ENVIRONMENT

Pesticides can become widely dispersed in the environment, mainly by the action of wind and water. Naturally, the most significant residues have been found in and near the areas of intensive use, but traces have also been found as far away as the Antarctic (Tatton and Ruzicka, 1967; Peterle, 1969).

Contamination of the aquatic environment by pesticides has been of public concern for the last two decades. The compounds most frequently incriminated are the organochlorine insecticides: DDT, TDE, endrin, heptachlor, aldrin, dieldrin, chlordane, toxaphene, and lindane. There is little doubt that DDT and, to a lesser extent, dieldrin have been the major contaminants. Traces of these chemicals can be found in almost all compartments of the world's ecosystem. Rivers, streams, lakes, estuaries, oceans, and bottom muds are major reservoirs for these pesticide residues. These pesticides reach aquatic environments through many routes (Edwards, 1973; Reese et al. 1972; Nicholson, 1970; Nicholson and Hill, 1970; U.S. Dept. of HEW, 1969).

Direct Application to Water

Many organic pesticides are applied directly on water to control aquatic weeds, non-game fish, and aquatic insects. Most of these applications are made for a particular purpose and the amount of pesticide used is closely controlled. To minimize undesirable side-effects, these operations are generally managed by professionals. However, control of the amounts used may be lax in massive applications (e.g., emergency mosquito control). In some instances, nontarget species may be very adversely affected.

Post-use dissipation is an extremely important factor in the application of herbicides for the control of aquatic weeds in irrigation and drainage canals, river banks and ditch banks. Most of the herbicides registered for use in aquatic situations have water use restrictions which require at least partial dissipation of the herbicide before normal water use is resumed (Timmer et al. 1970). The pathways of dissipation are almost as varied as the chemicals themselves. For example, volatilization is the most important means for the dissipation of aromatic solvents and acrolein. Adsorption processes predominate in the dissipation of herbicides such as diquat, paraquat, and possibly endothal. Biological and chemical degradation processes account for much of the disappearance of 2,4-D, silvex, dichlobenil and other herbicides.

Runoff and Sediment Transport

Runoff from terrestrial applications is generally considered as the major route of pesticide movement into the water environment. Intensive studies have demonstrated that runoff is probably the single most widespread and significant source of contamination (usually less than 1 ppb) of surface water (Nicholson, 1970; Nicholson and Hill, 1970). Terrestrial application of persistent pesticides also results in their being directly carried into surface waters and, through adsorption on silt and debris, transported into rivers and eventually estuaries.

During runoff the pesticide may be adsorbed on eroding soil particles, suspended in the runoff water, or both. Pesticides of low persistence naturally would have lower runoff than persistent ones. Chlorinated hydrocarbons, because of their persistence and low solubilities in water, are usually transported on the soil particles.

Soluble pesticides enter surface waters dissolved in the water runoff and drainage from the land. However, most of the pesticides reach the water with sediments washed from the land. The chlorinated hydrocarbons have been found extensively in surface waters, and in bottom sediments at 126 locations in the Mississippi River. The deposits are assumed to come from agricultural usage (Barthel et al. 1969).

Organic phosphates are generally more soluble than the chlorinated hydrocarbons. Herbicides, par-

ticularly the inorganic types, are highly soluble in water. The greatest danger from the runoff of soluble pesticides is in the period immediately following their application and prior to their becoming adsorbed onto soil particles. To some degree, this condition is under control in the major agricultural areas since weather conditions are closely observed and, to some extent, control the time of pesticide application. The same, however, cannot be said for household application.

Atmospheric Transport

Atmospheric transport to the aquatic environment can be due to (1) drift of pesticides applied aerially, (2) volatilization of the pesticides from the terrestrial environment, and (3) wind erosion.

Direct drift has been found to occur from spraying operations, especially when using aerial application (Frost and Ware, 1970). Fallout from aerial pesticide application is a principal source of water contamination (Spencer, 1971; Goldberg et al. 1971). High levels of atmospheric contamination by pesticides (DDT, toxaphene, parathion) were measured in agricultural areas such as Dothan, Ala.; Orlando, Fla.; and Stoneville, Miss. Higher pesticide levels were found when pesticide spraying was reported than when no spraying was in progress. Only p,p'-DDT and o,p'-DDT were found in the atmosphere at all nine sampling localities, in both urban and agricultural areas. Levels are highest in the agricultural areas of the South, and are generally lower in urban areas (Stanley et al. 1971).

Volatilization is a major pathway for loss of applied pesticides from plant, water, and soil surfaces (Spencer et al. 1973). It has been shown that nearly half the amount of DDT applied to the surface of the soil in field conditions may volatilize, thus making a slow, long-term contribution to the atmosphere (Lloyd-Jones, 1971). Volatilization of a pesticide depends on many other factors, such as air velocity, pesticide concentration, pesticide vapor pressure, temperature, relative humidity, soil water content, and bulk density of the surface soil (Igue, 1970).

Pesticides can be transported by wind and deposited in water far from an area of application; they are now considered to be universally present in the air. Their distribution to sites removed from application areas depends on prevailing patterns of wind circulation and deposition rates. The European-African land area was regarded as the source of chlorinated hydrocarbon insecticides found in airborne dust at Barbados (Risebrough et al, 1968). The insecticides (absorbed on the dust) were carried some 3,600 miles (6,000 km) by the transatlantic movement of the northeast trade winds. Recently, several studies have also presented evidence that the trade wind system of the Atlantic region may deposit amounts of chlorinated hydrocarbons comparable to those transported into the sea by major rivers (Sepa and Prospero, 1971; Bideleman and Olney, 1974; Gaskin et al. 1974).

Industrial and Municipal Wastes

Industrial waste constitutes perhaps the second most significant source of pesticides in water. The wastes from manufacturing and formulating plants, unless very closely controlled, contain pesticides. Additionally, the effluents from plants that use pesticides in their manufacturing processes may contain various amounts of pesticides. The distribution of DDT residues in *Emerita analoga* (Stimpson) along coastal California was recently investigated (Burnett, 1971). The findings showed that aquatic organisms near the Los Angeles County sewer outfall contained over 45 times as much DDT as those near major agricultural drainage areas. The probable source of this high concentration of DDT in the sewer outfall was thought to be a plant that manufactures DDT. This suggests that historically the buildup of residues in California coastal marine organisms could be attributed, to a significant degree, to industrial waste discharge rather than merely to extensive agricultural usage.

Pesticides can also enter water along with municipal wastes, such as sewage effluents. A 1971 review of pesticide monitoring programs in California prepared by an Ad Hoc Working Group of the Pesticide Advisory Committee to the State Department of Agriculture reported that substantial quantities of pesticides, mainly chlorinated hydrocarbons, have been discharged to surface waters through municipal and industrial waste discharges. The quantities of waste waters discharged were so large that even low concentrations of pesticides in water could result in a large emission. The report indicated that if large emissions from the Los Angeles County sanitation districts' outfalls have been occurring for a number of years, this one source may overshadow all other sources of DDT in southern California marine waters.

Effluents from sewers of large urban centers may contain small amounts of pesticides originating from home use but the great magnitude of discharge does not allow this source to be overlooked. It is significant to note that as much as 25 percent of the pesticides in the San Francisco Bay waters, amounting to 4,000 pounds per year, enter the bay through municipal and industrial wastewater discharges.

Researchers at the University of Georgia Marine

Station studied the effects of estuarine dredging on toxaphene concentrations of the marine biota (Durant and Reimold, 1972). Results indicated that, in the estuary, the sediments near a toxaphene plant outfall in Terry Creek, Brunswick, Ga., were found to be contaminated with toxaphene approaching 2,000 ppm, and oysters collected two miles from the outfall were found to contain residue levels near 6 ppm. In a later study Reimold and Durant (1974) found that the monitoring of dredge spoil, fauna, and flora showed toxaphene concentrations to be higher during dredging than before or after. The concentrations in oysters ranged between 2.0 and 5.0 ppm. The eastern oysters, reported to be the best biological monitors, did not demonstrate large changes in toxaphene content resulting from the dredging. A report released by the Georgia Marine Science Center in 1973 discussed the effects of toxaphene contamination on estuarine ecology. It indicates that as the toxaphene content in the plant effluent decreased during the 3-year study period, the toxaphene content of fauna, flora and sediments decreased also. This reflects in part the pollution abatement practices initiated at the toxaphene production plant which greatly reduced the quantities of toxaphene in the plant effluent (Reimold, Adams and Durant, 1973).

Accidents and Spills

Accidents and spills occur during storage, packaging, transport, disposal, and application and may be very serious because of the usually highly concentrated chemicals. Although they may affect only a localized area for a short period of time, the possibilities are almost unlimited and much needs to be done to bring this unintended entry of pesticides into the aquatic environment under control.

On August 11, 1974, parathion, a highly toxic organophosphorus insecticide, and dead fish were discovered in the Yuma main canal, that city's source of drinking water. Fortunately, none of the poisoned water reached the city treatment plant before the accident was discovered. No injuries or death were reported, but the California Fish and Game Department estimated 10,000 fish were killed. Authorities said they were unable to determine how the insecticide was put into the canal (San Francisco Chronicle, Tuesday, August 13, 1974).

FISH KILLS

Fish mortalities result from a variety of causes, some natural and others man-induced. Fish kills brought about by man may be attributed to municipal or industrial wastes, agricultural activities, transportation operations, and other projects such as water manipulations that significantly alter the quality of the aquatic environment.

Fish are significant indicators of water quality. When fish die in large numbers at one time, it is usually a sign of an unnatural phenomenon within the aquatic environment. The destruction of fish not only indicates a severe problem occurring in the water environment, but reduces a natural resource of recreational and often economic value.

The Environmental Protection Agency (EPA) publishes an annual report on fish kills caused by pollution since 1961. This report is the result of cooperative teamwork between EPA, state pollution control agencies, and private citizens. It includes reports of fish kills where water pollution is known or suspected to be the cause of death. Since numerous kills resulting from pollution go unnoticed or unreported, the report cannot be considered complete. Despite these gaps, the data compiled in these annual reports provide useful and basic information, serve to point out potential pollution problems, and alert officials and the public itself to the need for stricter safeguards to keep dangerous substances out of the nation's water resources. In the 1972 report, for the first time since inception, every state in the Union participated.

Table 3 contains a 10-year (1963-1972) fish kill summary by source of pollution. The 17.7 million fish killed in 1972 brought the cumulative total of all fish reported killed by water pollution since 1963 to 225 million. While there was a 76 percent decrease in fish reported killed in 1972 compared to the record 73.6 million fish killed in 1971, the year 1972 was the fifth highest year in the number of fish reported killed.

Industrial pollution was identified as the largest killer of fish during the 10-year period. About 85.5 million (38 percent) fish died from this type of pollution. Municipal operations, which handle wastes from cities, ranked second in the total number of fish killed—60.4 million or 26.8 percent. Unknown operations, a new classification added in 1971 to include fish kill which cannot be linked to a specific pollution source, accounted for 39.1 million (17.4 percent) of the fish kill. This resulted from 219 reported incidents resulting in approximately 35.3 million fish killed in 1971 alone. Agricultural operations ranked fourth, and were responsible for the killing of 17.5 million (7.8 percent) fish. The fifth ranking category—other operations—accounted for the death of 17.3 million (7.7 percent) fish.

Table 4 provides a 10-year summary of fish kill by subcategories of the agricultural operations. It

Table 3.—Fish kill summary by source of pollution (No. of fish killed)

Year	Agricultural	Industrial	Municipal	Transportation	Other Operations	Unknown	Total
1963	560,967	2,690,601	914,379	78,388	100,912	2,471,283	6,816,530
1964	1,415,092	12,525,301	3,893,687	22,211	13,423	—	17,869,714
1965	1,390,136	3,763,948	5,911,604	306,810	20,941	—	11,393,439
1966	1,259,599	4,622,790	1,347,248	102,631	1,410,569	—	8,742,837
1967	1,607,267	8,087,091	643,304	143,123	638,288	—	11,119,051
1968	375,548	6,255,713	6,791,464	825,365	578,124	—	14,826,214
1969	6,293,880	26,680,182	1,155,027	2,057,030	2,450,909	—	40,637,028
1970	1,809,541	9,588,949	6,601,845	465,005	3,820,994	—	22,286,334
1971	1,023,337	4,652,392	24,798,432	664,180	7,257,478	35,257,226	73,653,045
1972	1,807,555	4,694,390	8,360,594	456,526	1,028,869	1,369,284	17,717,218
Total	17,542,922	85,561,357	60,417,584	5,121,269	17,320,485	39,097,793	225,061,410
% Total	7.8%	38.0%	26.8%	2.3%	7.7%	17.4%	100%

Source: Data extracted from "Fish Kills Caused by Pollution" series, published annually by the U.S. Environmental Protection Agency.

shows that pesticides comprised the leading source of agricultural pollution, with 11.4 million (64.9 percent) fish fatalities. Reports of fish kills under pesticides include incidents in which spraying machinery and pesticide containers were cleaned or dumped into nearby streams, lakes, or estuaries. However, the majority of reported incidents resulted from pesticides being washed into water by rainfall after spraying for agricultural purposes.

Fish kills by type of water are summarized in Table 5. For the period 1963-1972, approximately 60 percent (134.5 million) of the total reported fish were killed in freshwater, while 37 percent (83.4 million) fish fatalities occurred in estuary-type water. In 1971, about 77 percent (56.4 million) of the total reported fish were killed in the estuary-type water, and for the first time since the annual report system started in 1960, more fish were reported killed in estuarine waters than in freshwater. The large kill in 1971 was primarily due to a number of large kills totaling 31.4 million fish which were reported in two localized areas—Escambia Bay, Fla., and Galveston Bay, Tex. It should not be interpreted as a national trend. The number of fish reported killed in estuary water in 1972 decreased appreciably from the number reported in 1971. Nevertheless, the significant increase of fish kills in the estuaries since 1968 is of great national concern since estuaries serve as breeding and nursery grounds for many species of marine fish.

MONITORING OF PESTICIDES IN RIVERS AND ESTUARIES

Reports of insecticide residues in streams and rivers in the United States began to appear about 10 years after the introduction of organochlorine insecticides and it soon became obvious that small amounts of these insecticides occurred in many waterways. At present, all of the different organochlorine insecticides have been reported from U.S.

Table 4.—Fish kill summary by agricultural operations (No. of fish killed)

Year	Pesticides	Fertilizers	Manure-silage Drainage	Total
1963	401,415	1,400	158,152	560,967
1964	191,167	67,040	1,156,885	1,415,092
1965	770,557	2,697	616,882	1,390,136
1966	217,406	1,200	1,040,993	1,259,599
1967	329,130	10,000	1,268,137	1,607,267
1968	325,194	15,116	35,238	375,548
1969	5,982,877	73,569	237,434	6,293,880
1970	1,409,794	4,069	395,678	1,809,541
1971	264,504	65,760	693,073	1,023,337
1972	1,500,147	30,944	276,464	1,807,555
Total	11,392,191	271,795	5,878,936	17,542,922
% Total	64.9	1.5	33.6	100

Source: Data extracted from "Fish Kills Caused by Pollution" series, published annually by the U.S. Environmental Protection Agency.

Table 5.—Fish kill summary by type of water (No. of fish killed)

Year	Fresh	Salt	Estuary	Total
1963	5,478,130	1,234,370	104,100*	6,816,530
1964	15,334,699	2,531,700	3,915	17,869,714
1965	11,255,658	102,121	35,660	11,393,439
1966	8,698,607	19,050	25,270	8,742,927
1967	11,066,012	30,000	3,039	11,119,051
1968	9,869,851	1,888	4,954,475	14,826,214
1969	34,958,048	641,150	5,039,830	40,637,028
1970	11,991,099	536,000	9,759,235	22,286,334
1971	15,205,913	2,014,914	56,432,218	73,653,045
1972	10,689,294	37,766	7,010,158	17,717,218
Total	134,544,711	7,148,889	83,367,900	225,061,500
% Total	60	3	37	100

Source: Data extracted from the "Fish Kills Caused by Pollution" series published annually by the U.S. Environmental Protection Agency.

*"Brackish water."

rivers, sometimes in large quantities. DDT has been found in the largest amounts, but it is not always the most common residue, although some rivers have contained it in all the sampling programs. There have been relatively few reports of residues of chlordane, endosulfan, and toxaphene in U.S. waterways, although these are commonly used in the U.S. Since 1962, there have been surveys of pesticides in most of the major waterways. A National Pesticide Monitoring Network was set up in 1964 as a cooperative effort of the Federal departments making up the membership of the Federal Committee on Pest Control. It was initially designed on the basis of the minimum monitoring needed to establish baseline levels of pesticides in substrates of food, humans, soil, water, air, wildlife, fish, and estuaries and to assess changes in these levels. This program continued until the passage of the Federal Environmental Pesticide Control Act of 1972 (Public Law 92-516) at which time the program received legislative status. The Environmental Protection Agency (EPA) had taken important steps to assure an uninterrupted study of environmental residues and to enlarge and upgrade the program. Additionally, as the focal point of legislative authority, EPA accepted the responsibility of financing several of the large projects by contracts with another government agency having field staff qualified to do the work.

Pesticides in the surface waters of the U.S. for the period 1964–1968 were reported by Lichenberg in 1970. The monitoring was restricted to chlorinated insecticides. It was found that individual insecticides, when present, were in fractions of a part per billion (ppb).

A study entitled "Pesticides in Selected Western Streams" was initiated in 1965 by the U.S. Geological Survey as a contribution to the national program. The period of 1965 through September 1968 is covered by two publications (Brown and Nishioka, 1967; Manigold and Schulze, 1969). In the 1967–1968 period, 62.5 percent of the "whole water" sampled contained no detectable insecticides (minimum detectable level 0.01 ppb) and the remaining had individual pesticide levels only in fractions of a part per billion. The pesticides monitored were rather restricted in number (DDT and its metabolities; aldrin; dieldrin; endrin; heptachlor and its epoxide; lindane; chlordane; toxaphene; endosulfan; phosphorothioates; PCB's; and three herbicides: 2,4-D; 2,4,5-T; and silvex).

During the period 1968–1971 (Schulze, Manigold and Andrew, 1973) compounds found included the common chlorinated insecticides and herbicides. "Heptachlor and its expoxide were not detected during the 3-year period, and aldrin was found only once. DDT was the most frequently occurring insecticide, and 2,4,5-T the most common herbicide. The amounts observed were small; the maximum concentration of an insecticide was 0.46 mg/liter for DDT, and of an herbicide 0.99 mg/liter for 2,4-D ... Concentrations were highest in water samples containing appreciable amounts of suspended sediments." Pesticide concentrations never exceeded the permissible limits established for public water under the Water Quality Criteria published by the Department of the Interior in 1968, although in several instances concentrations were measured that were above the environmental levels of 0.05 mg/liter recommended for marine and estuarine waters.

Organochlorine insecticides are not usually in solution in water because they are all of very low solubility. Tests on river water emptying into the ocean, even after draining land heavily sprayed with pesticides, may contain relatively low concentrations of pesticides. Yet, in certain conditions, such as during periods of high turbidity caused by sediment load, it seems probable that rivers could carry a heavy concentration of pesticides to the sea. The mud at the bottom of many rivers is heavily contaminated with pesticides and will continue to be a reservoir for periodic future contaminations.

As a part of a study to assess the potential contamination of the San Francisco Bay from chlorinated hydrocarbon compounds, bottom materials from 26 streams tributary to the bay were analyzed for chlordane, DDD, DDE, DDT and PCB residues. These compounds were found in all stream bed samples analyzed, thus illustrating their widespread distribution in the bay. Chlordane was ubiquitous, with a concentration range similar to that of the other compounds (Law and Goerlitz, 1974).

Accumulation of pesticides in bottom sediments plays a very important role in their disappearance from contaminated water. Pesticide concentrations in the sediments may be much higher than the concentrations in the water. Studies in major agricultural river basins in California revealed that an average pesticide concentration of 0.1 to 0.2 ppb in river water may mean that bottom sediments contain 20 to 100 ppb.

It can be expected that rivers would carry pesticides down to the sea so that large amounts of residue could be deposited in estuaries and near the mouth of rivers. However, there is surprisingly meager evidence of pesticide residues in these areas. The report on "Chlorinated Hydrocarbons in the Marine Environment" (National Academy of Sciences, 1971) estimated that "as much as 25 percent of the DDT compounds produced to date may have been transferred to the sea. The amount of DDT

compounds in the marine biota is estimated to be less than 0.1 percent of total production, yet this amount has produced a demonstrable impact upon the environment."

It was estimated that 1.9 metric tons of pesticides are carried into the San Francisco Bay annually by the Sacramento and San Joaquin Rivers (Risebrough et al. 1968), and that 10 metric tons reach the Gulf of Mexico each year from the Mississippi River. Although these may seem very large amounts, they are small relative to the pesticide usage in the vicinity of these rivers. These residues represent no more than 0.1 percent of the amounts of pesticides used in the area supplying water to the estuaries, but some may be rapidly taken out to sea because of the strong tidal exchange in the San Francisco Bay (Frost, 1969).

The Estuarine Monitoring Program was organized by the Bureau of Commercial Fisheries in 1965 to monitor the chlorinated hydrocarbon insecticides reaching the major estuaries on the Atlantic, gulf and Pacific coasts. In July 1972, the National Marine Fisheries Service of NOAA withdrew its financial support and EPA took over the responsibility of the entire estuarine study. This study has been redesigned to include marine life in all of the 200 primary estuaries listed in the "National Estuarine Survey."

A recent publication entitled "Organochlorine Residues in Estuarine Mollusks, 1965–72—National Pesticide Monitoring Program" reports the findings covering 15 coastal states during a 7-year period (Butler, 1973). Shellfish were chosen as 'indicator' organisms because they are sessile and readily concentrate pesticides from the environment, yet the chemical is flushed out of their tissues at a uniform rate when the pesticide is no longer present in the environment (Duke, 1970). The findings of this study are summarized as follows:

1. The analyses of 8,095 samples for 15 persistent organochlorine compounds showed that DDT was the most commonly identified pesticide and occurred in 63 percent of all samples analyzed. In most cases, estuarine pollution with DDT was intermittent and at levels in the low parts-per-trillion range. The maximum DDT residue detected was 5.39 ppm.

2. In most estuaries monitored, detectable DDT residues have declined in both number and magnitude in several species of estuarine mollusks in recent years. DDT pollution peaked in 1968 and has been declining markedly since 1970.

3. Dieldrin was the second most commonly detected compound with a maximum residue of 0.23 ppm.

4. Other organochlorine residues (endrin, mirex, toxaphene, and polychlorinated biphenyls) were found only occasionally and generally at low levels, with exception of toxaphene.

The report further points out that "at no time were residues observed of such a magnitude as to imply damage to mollusks; however, residues were large enough to pose a threat to other elements of the biota through the processes of recycling and magnification." It is also of interest to note that 38 samples (0.5 percent) had DDT residues exceeding 1.0 ppm. These samples were collected in California, Florida and Texas in drainage basins having intensive agricultural development.

With regard to California, where approximately 22 percent of the nation's pesticides are sold, the report states:

> DDT residues in mollusks were consistently larger in California than in any other area monitored with the exception of a single station in south Florida. There is a clear pattern of maximum pesticide residues being correlated with proximity of the monitoring station to runoff from agricultural lands. In southern California, where most samples contained typically large residues, residues were consistently higher at Hedionda and Mugu Lagoons, the recipients of agricultural runoff waters, than at Anaheim Slough which receives intermittent runoff from the urban and industrialized sections of Los Angeles. Residues in samples from estuaries draining the intensely cultivated central and southern parts of the state were larger, by one order of magnitude usually, than those in samples collected from watersheds north of San Francisco Bay where dairy land predominates.

A preliminary report regarding the influence of pesticide runoff in Monterey Bay, Calif., points to the Salinas River as the source of pesticide pollution (Haderlie, 1970). This is the only major river entering the Bay, and it drains the 100 mile long Salinas Valley with a drainage area of 4,000 square miles. The Salinas Valley is one of the richest agricultural areas in California, specializing in lettuce, broccoli, celery, sugar beets and so on. During a 10-year period between 1960 and 1969, it is conservatively estimated that 63 tons of DDT were sprayed on the crops and soil of the valley each year. Students at the Hopkins Marine Station near the bay made a study during the late spring of 1969 of the DDT content of the sand-dwelling mole crab, *Emerita*. This animal does not seem to concentrate DDT content in high concentrations. *Emerita* taken from the open coast outside Monterey Bay had too little DDT in their tissue to be measurable, yet *Emerita* taken from sand near the mouth of the Salinas River had DDT concentrations of 0.14 ppm. In addition, it was noted that during the late spring and summer of the same year, more dead seabirds were found along the shore of Monterey Bay than ever before. At one period 440 dead birds were found on one stretch of

beach less than a mile long. Of these, 37 percent had been oiled, 14 percent shot, and 49 percent had died of unknown causes. The livers of this third group of birds were subjected to tests for chlorinated hydrocarbons. The dead seabirds contained concentrations of pesticides as high or higher than that recorded anywhere. A brief summary of the data is as follows:

DDE Concentrations in Livers of Dead Seabirds

Brandt' cormorants	107–155	ppm
Western grebes	192–292	ppm
Fork-tailed petrel	373	ppm
Ashey petrel	412	ppm
Ring-billed gull	805	ppm

Although one cannot be certain that it was the high concentrations of DDT residues that killed these animals, circumstantial evidence seems to indicate pesticides as the cause of death.

In an earlier study concerning the chlorinated hydrocarbon pesticides in California bays and estuaries, it was found that pesticide residues in estuaries geographically isolated from agricultural areas seldom exceeded 100 ppb. Pesticide residues frequently exceeded this level in agricultural regions and were found as high as 11,000 ppb in shellfish from polluted areas (Modin, 1969).

A similar study was conducted to investigate the chlorinated hydrocarbon residues in shellfish (Pelecypoda) from estuaries of Long Island, N.Y. (Foehrenbach et al. 1971). Results indicate that the distribution of residues could at times be correlated with agricultural use or type of community in the watershed surrounding the various stations.

EFFECTS OF PESTICIDES ON ESTUARINE ORGANISMS

It is becoming apparent that increased information is necessary about the distribution, concentration, and elimination of pesticides in estuarine areas. Most literature reports on pesticides in estuaries concern chlorinated hydrocarbons such as DDT, endrin, dieldrin, and aldrin. However, the overall picture of the dynamics of these compounds in the estuarine environment is obscure.

Potentially more hazardous are pesticides that persist in the environment and move up in the food chain. For example, small amounts of chemicals adsorbed by plankton and insects are transferred in increasing concentration to fish, birds, animals, and eventually to man. There is evidence that concentrated pesticide residues act adversely on the reproduction and behavior of certain wildlife species and may threaten their survival. In certain instances, pesticide residues accumulated through food chains have been implicated as causing death of contaminated animals. For example, the loss of fish-eating waterbirds at Tule Lake and Clear Lake in California and the reduction of pelican population on the Pacific coast were attributed to pesticides which had traveled through biological networks and accumulated in the bodies of these birds.

Several review papers have recently been published which bear on the subject of pesticides and estuarine organisms. Butler (1971) discussed the influence of pesticides on marine ecosystems; Foehrenbach (1972) described experiments on chlorinated pesticides in estuarine organisms; Whitacre (1972) et al. reviewed the pesticides and aquatic micro-organisms; and Edwards (1973) summarized the literature concerning the persistent pesticides in the environment. Perhaps the most comprehensive review on the subject is the paper written by Walsh (1972) entitled "Insecticides, Herbicides, and Polychlorinated Biphenyls in Estuaries."

Phytoplankton

Phytoplankton probably act as primary concentrators of pesticides in water. There is evidence that these toxicants reduce photosynthesis, but bioconcentration by algae may be more important ecologically because they transfer many materials to higher trophic levels. Under laboratory conditions, algal samples were found to contain dieldrin concentrations ranging from 0.1 to 100 milligram per kilogram dry weight. Algal concentrations of dieldrin were as much as 30,000 times those occurring in the water (Rose and McIntire, 1970). Algae are the primary producers in the aquatic environment. Grazers and higher consumer organisms depend upon algae as a food source, either directly or indirectly.

Extensive pesticide accumulation by select algal communities constitutes a contaminated food source for animals which feed on those forms.

Invertebrates

Organochlorine insecticides are so toxic to aquatic invertebrates that these aquatic organisms have long been used to bioassay insecticides. A more complex problem than that of toxicity is the accumulation of

pesticides in various aquatic organisms. When pesticides reach water, they are rapidly adsorbed by the bottom sediment, plankton, algae, aquatic invertebrates, aquatic vegetation, and fish. Such accumulations, often increasing through different trophic levels in aquatic organisms, have been demonstrated experimentally by several workers and are well-known.

Organochlorine insecticides are relatively insoluble in water but seem to have a great affinity for the tissues of aquatic invertebrates. Most of these aquatic organisms seem to contain some residues of these insecticides; the only difference is that those from the more remote areas such as Antarctica seem to contain less than those from more temperate regions closer to main usage areas of these insecticides. Other than this, the amount reported does not seem to differ significantly between organisms that live in freshwater, seawater, lakes, rivers, or estuaries.

Organic particulate matter of estuaries is an important food source for benthic organisms. In areas where most of the primary production occurs through the slow bacterial decomposition of such plant materials as marsh grasses, rushes, and mangroves, a release of pesticide residues to the water may occur. This decaying plant detritus becomes an enriched food source when utilized by other microorganisms. The mud dwelling fiddler crab concentrated DDT residues in its muscle tissues after consumption of detrital food material from sediment (Odum et al, 1969). In the field, DDT residues appeared to be associated with particulates in the range of 250 to 1,000 microns. Because crabs and other detritus-feeding animals consume particulate matters of that size range, the authors concluded that organic detritus particles constitute a reservoir from which the pesticides enter the food chain.

Oysters extract nutrition from the aquatic environment by filtering particles of food from the water which is continuously passed in and out of their bodies. The organisms accumulate pesticide-contaminated particles in this fashion. Oysters efficiently store trace amounts of pesticides and are used as estuarine monitoring organisms by the Gulf Breeze Laboratory of EPA. They provide a sensitive index of the initiation, duration and extent of chlorinated hydrocarbons' pollution in an estuary. The concentration or elimination of residues in oysters is dependent upon the level of pollution, the water temperature, and their position relative to the water flow. To eliminate DDT residues of 150 mg/kg may require three months or longer while residues of less than 0.1 mg/kg may disappear in about two weeks.

Chronic exposure to sublethal concentrations of pesticides can reduce productivity of estuarine fish and shellfish (Butler, 1969). The insecticides DDT, toxaphene, and parathion are toxic to oysters at concentrations of approximately 1 ppm in water. When exposed to only 1.0 ppb of each of these insecticides separately, no effects were noted in young oysters (Loew et al. 1971). The population of marsh fiddler crabs was significantly decreased by treatment of their habitat with abate, an organophosphorus insecticide, according to Ward and Howes (1974). The population decrease may have resulted from sublethal effects which rendered the animals more vulnerable to predators.

The effects of organochlorine insecticides on aquatic invertebrate populations may constitute both direct and indirect hazards to other animals. The most susceptible of these organisms are the smaller crustacea, which are killed by amounts of the order of 1.0 ppm $\times 10^3$. Still susceptible, but less so, are the larger crustacea.

Invertebrates that are not killed may exhibit a variety of indirect effects of the pesticides, such as loss of coordination and other behavioral symptoms, loss of fertility, or retardation of growth (Edwards, 1973). Considerable changes in the species' habitat structure may occur if predators and their prey differ in susceptibility to these chemicals. All of these effects may greatly influence overall populations of aquatic invertebrates and, since these are a major food source for fish, may exert strong environmental pressure on fish populations. Moreover, the residues in their bodies may accumulate in the tissue of fish and other animals that eat them and in this way exert further environmental stress.

Vertebrates

The literature on residues of organochlorine insecticides in fish is very extensive. One can only consider the subject very generally and select data from some of the recent studies, which should serve to provide a general assessment of current status of pesticide levels in fish and other vertebrates. It is well known that marine fishes contain insecticides and, in general, are less susceptible to poisoning than some other aquatic forms (Table 6).

In general, organophosphorus compounds tend to be more acutely toxic than the organochlorines, and herbicides are less toxic than insecticides (Butler, 1971). Effects of organophosphates may last for only hours or days, whereas the organochlorines are more persistent and exert their effects following bioaccumulation and magnification in trophic pyramids.

Of all the organochlorines, DDT is by far the most common and occurs in the greatest amounts. There

Table 6.--Acute Toxicity (24 hours) of 240 Pesticides to Estuarine Fauna

Pesticide (ppm)	No Effect	Toxic to 20% of Test Population		
	1.0 %	0.1–1.0 %	0.01–0.1 %	0.001–0.01 %
Fish	46	16	28	10
Shrimp	33	14	33	20
Oysters	41	21	33	5

Source: Butler, 1971

is some evidence that the amounts of organochlorine residues accumulated by fish are influenced by the lipid content of the fish; the more lipid they contain, the less susceptible they are to the pesticide. Similarly, the larger the fish, the greater the concentration of residues they may contain. Hannon et al. (1970) found that fish in the higher trophic levels tended to have a large proportion of the organochlorine residues that they contain in the form of metabolites such as DDE, DDD, heptachlor epoxide, and dieldrin. It has been reported that there were greater concentrations of organochlorine residues in fish from higher trophic levels, even when movement of the residues through a food chain was impossible (Hamelink et al. 1971).

The amount of pesticide in a field population may also vary over the seasonal cycle in different species. Concentrations of DDT in the *Triphoturus mexicanus* taken from the Gulf of California increased with size of the fish (Cox, 1970). The annual variation in the content of DDT and its metabolites in five species of fish from the estuary near Pensacola, Fla., was observed by Hansen and Wilson (1970). They stated that pesticide residues in benthic fishes which remain in one location are better indicators of pollution than residues in pelagic fishes.

Fishes are generally more resistant to pesticides than shrimps and oysters but are more sensitive than other vertebrates to organochlorine pesticides. Fishes do, however, vary in their responses to avoid water containing DDT, endrin, Dursban and 2,4-D. When fish were given a choice of two concentrations of the pesticides, the highest concentration of 2,4-D was avoided, but the highest concentration of DDT was preferred (Hansen, 1969). The author suggested that if the capacity to avoid a pesticide is controlled genetically, fish which survive pollution by this means would produce more offspring with the capacity to avoid the chemical. Thus, genetic ability to avoid pesticides would have survival value for the species. Fabacher and Chambers (1971) found that mosquitofish probably result from other factors in addition to increased lipid content. These may include decreased uptake, "resistant" nervous tissue, stress-tolerance, or others. The total mechanism or resistance is probably a complex interaction of many, many factors.

Organochlorine insecticides in the estuarine environment constitute both direct and indirect hazards to fish and to those organisms that feed on fish. The indirect aspect is that plankton and other fish food may adsorb large quantities of these chemicals, thus poisoning the fish that eat them. Alternatively, when the fish take up residues, they may be affected by them. Many indirect sublethal effects of organochlorine residues on fish have been reported; they include lower disease resistance, sub-normal feeding rates, and reproductive failure, to mention a few. Another hazard caused by pesticide residues in fish results from the fact that these animals are a major source of human food. If residues in fish are large, they may accumulate in man to a possibly hazardous level. In countries with more stringent legislation, these fish would be unsalable as human food. The rejection of fish products because of high concentrations of pesticides, e.g., DDT in California jack mackerel, can pose a hardship to fishermen and an economic burden on governments.

Estuarine Birds and Mammals

Extensive literature exists detailing effects of pesticides on estuarine birds (Moore and Tatton, 1965; Heath et al. 1969; Anderson et al. 1969; Lamont et al. 1970; Lamont and Teichel, 1970). A recent report by Johnston (1974) indicates a decline of DDT residues in migratory songbirds killed when the birds flew into television towers in Florida. The results showed a progressive decline in the concentration of DDT and its metabolites (DDD and DDE) in their fat depots for the period 1964 to 1973. This decline is apparently correlated with decreased usage of DDT in the United States during the same time, according to the author.

Little is known, however, about pesticides in mammals. DDT was found in seals from the Antarctica and in grey seals, common seals, and harbor porpoises in England and Scotland. Pesticides have also been found in whales (Wolman and Wilson, 1970). Blubber of grey whales and sperm whales from waters near San Francisco contained up to 6.0 ppm of DDT.

MINIMIZING PESTICIDE POLLUTION IN THE ESTUARINE ENVIRONMENT

Estuaries are vital nursery and feeding grounds for major commercial fisheries. The possibility that they might act as "a sink for the persistent pesticides" is intolerable (Butler, 1971).

There is little doubt that the persistent pesticides, particularly DDT and dieldrin, are major long-term contaminants of the aquatic environment, and small traces can be found in almost all compartments of our ecosystems. The situation with respect to estuarine pollution from pesticides emphasizes the need for more basic research. Investigations to establish safe limits for toxicants in water cannot be done on a short-term basis. Effective research in this area requires long-term commitment of government agencies and the public at large.

Use of Alternative Pesticides

The main problem of finding alternatives for persistent insecticides is not that suitable insecticides cannot be developed, but is economic, because persistent insecticides can be made and sold so cheaply. Additionally, one dose gives protection against soil pests for several seasons. The recent shift in pesticide usage from the organochlorines to the so-called "substitutes" or "non-persistent" pesticides is an encouraging trend. However, the less persistent substitutes such as organophosphates and carbamates, which are gaining in popularity, are also more toxic to man and certain other non-target organisms. Although there is a considerable knowledge about the residues of these substitutes and about their metabolism in target organisms, little is known about their overall effects on our aquatic environment.

Metcalf et al. (1972) demonstrated the possibilities of producing selective and biodegradable analogues of organochlorine insecticides using a model ecosystem for the evaluation of pesticide biodegradability and ecological magnification(1972a). Metcalf (1972b) emphasized that the principle of selectivity and biodegradability must be included in the future development of better pesticides if we are to begin to solve the many problems of human ecology and environmental pollution arising from pest control.

The use of biological agents is promising. Two bacterial pesticides are now commercially available and have registered with EPA—*Bacillus popilliae* and *B. thuringiensis*. These insecticides have a number of important advantages. They effectively control specific insects, do not harm humans, livestock, fish, wildlife, and beneficial insects, and do not damage plants. Furthermore, insects do not become resistant to these control agents. On the other hand, the bacterial insecticides are not as fast-acting as most conventional chemical insecticides. Usually, bacterial insecticides are a more expensive means of insect control. And poor weather conditions may prevent proper control.

Better Use of Pesticides

Many of the pesticide problems that have arisen through the use of persistent pesticides are due to careless use as well as unnecessary use of chemicals. Too often, large areas of land have been indiscriminately sprayed to control forest insects, mosquitoes, or agricultural pests. Aerial sprays fall on all parts of an ecosystem. Such spraying operations should be severely limited, even with non-persistent pesticides. A notable example is the disastrous effect on aquatic animals resulting from the use of mirex to control fire ants in the southeast United States. This pesticide is highly persistent in the natural environment and has been shown to be moderately carcinogenic when injected in laboratory mice. Subsequent long-term studies have demonstrated chronic toxic effects on crabs and shrimp. A national survey of oysters and other shellfish demonstrated that mirex is the fourth most commonly found pesticide residue. It was also reported that mirex contaminates shellfish in estuarine drainage areas of southern states.

New formulations are now available to slowly release pesticides at the time needed. Recently, EPA granted final label approval for the first commercial marketing of a microencapsulated pesticide, Pennwalt Corp's Penncap-M, which consists of a suspension in water of polyamide microspheres containing methyl parathion. Such formulation offers a promising approach to achieving more efficient, more economical, safer, and more controlled use of pesticides.

Integrated Pest Management

In recent years, the concept of integrated pest management has been re-emphasized. The goal is to bring the best of all available control techniques to bear against pest problems rather than to rely solely on chemical pesticides. Its strategy is one of "management and containment" rather than "seek and destroy." This method combines the intelligent manipulation of natural control techniques with the essential use of pesticides; it has been successfully applied in several parts of the world. In Israel, effective programs have been set up against citrus pests; in California for pests on cotton, alfalfa and grapes; and in central Europe for pests in orchards.

Removal of Pesticides

Runoff from agricultural land is an important source of pesticides in rivers and estuaries. Controlling such runoff through good soil conservation practices would substantially decrease the contamination

of water. In regard to industrial and municipal discharge, efforts should be made to increase the efficiency of extraction of pesticides from the water and other detoxification processes such as microbial degradation and energetic radiation (ultraviolet or gamma ray).

Better Understanding of Estuarine Ecosystems

There is an urgent need for detailed and extensive studies on the effects of pesticides in the estuarine and marine environments. Only with additional scientific data will a sound estuarine management policy be possible. Immediate attention is required to clarify the effects of environmental variables on the acute toxicities of pesticides to sport and commercial fishes as well as on their effects on various elements in the food web. In addition to laboratory results, information is needed on toxicity under natural conditions. For example, what effects do water chemistry, temperature, biota, and many other environmental factors have on toxicity? What is the significance of the size, age, and condition of the fish? This information is essential if sound predictions concerning the biological effects of pesticides are to be made.

Little is known about the long-term, sublethal effects of pesticides on fishes or other aquatic organisms. To gather information requires prolonged exposures of fishes to variable concentrations of the toxicant in question.

Much information is needed on the manner in which an "unstressed" estuarine system operates before one can properly assess the impact of a pesticide or other chemicals on such systems.

The interactions of the various communities with each other and with their physical environment could be affected by a pesticide. One way to quantify such effects is to construct an experimental ecosystem in which several species of organisms and their substrates can be subjected to the pesticide (Duke, 1974) to obtain information on rates, routes and reservoirs of accumulation. Once a satisfactory compartmental model is developed, substituting different data enables the impact of different variables to be evaluated.

Governmental Control of Pesticide Use

On October 21, 1972, the President signed into law H.R. 10729, the Federal Environmental Pesticide Control Act of 1972 (Public Law 92-516), amending the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947. All provisions of the Act must be in effect by October 1976. The new act, FIFRA as amended, extends federal registration and regulation to all pesticides, including those distributed or used within a single state. It requires the proper application of pesticides to insure greater protection of man and the environment.

The FIFRA was administered by the U.S. Department of Agriculture until the authority was transferred to the Environmental Protection Agency (EPA) when it was established in December 1970. EPA has the authority to cancel a pesticide registration if it was later determined that the directed use of the pesticide posed a serious hazard to man or the environment. EPA also can suspend a pesticide registration and stop interstate shipments immediately. Unlike cancellation, suspension orders can be initiated only when the products present an "imminent hazard."

Within the last few years EPA has taken several control actions against a number of persistent organochlorine pesticides. In 1971 EPA initiated cancellation proceedings under FIFRA against DDT, mirex, aldrin, and dieldrin. After extensive hearings, the agency announced cancellation of nearly all remaining uses of DDT in June 1972, based on potential future hazard to man and his environment. The agency has also limited the use of mirex against the imported fire ant in the southeastern United States, primarily because of hazard to aquatic life.

On August 2, 1974, EPA issued suspension notices for aldrin and dieldrin, citing evidence of "imminent hazard." On October 1, 1974 EPA administrator Russell Train ordered an immediate suspension of further production of aldrin and dieldrin, because of evidence they may cause cancer. This order became final on May 27, 1975 when EPA Chief Administrative Judge H.L. Perlman announced that the U.S. Court of Appeals for the District of Columbia had ruled that aldrin and dieldrin create "imminent hazards" when used.

On November 26, 1974, EPA gave notice of its intent to cancel all registered uses of heptachlor and chlordane which are now in widespread use for home, lawn, and garden pest control. Their major agricultural use is on corn crops. On July 30, 1975, EPA ordered an end to the manufacture and sale of the two pesticides, citing an imminent human cancer hazard and the available substitute pesticides now registered with EPA. However, this suspension order allowed continued production of these two pesticides for termite control by ground insertion and the dipping of roots and tops of nonfood plants.

In 1971 and 1972, EPA issued suspension and

cancellation notice for mercury pesticides. A variety of organic mercury compounds are used in agriculture as fungicides and in the paper industry as slimicides. If they find their way into the aquatic environment they are readily converted under anaerobic conditions to methyl-mercury compounds, which are very readily taken up by aquatic organisms and accumulated in the food chain.

SUMMARY

Trends in the production and use of pesticides in recent years indicate that there will be an increased demand for pesticides during the next decade due to the mounting demand for food and the need to reduce the devastation of food supplies by insects, weeds, and diseases. According to a World Health Organization estimate, about a third of the agricultural products grown by man worldwide are consumed or destroyed by insects. There is little doubt that pesticides will continue to play an important role in the production of food.

The most difficult pollution control problem—for estuarine and coastal waters—is posed by wastes which do not come from a point source, such as pesticides from runoff and drift. Agricultural pesticides enter the estuarine environment through their direct application to water, runoff and sediment transport from the treated fields, atmospheric transport, industrial and municipal waste discharge, accidents and spills.

Fish kills in the United States are well known. Agricultural operations ranked fourth in the total number of fish killed, and pesticide was the leading source of agricultural pollution, with 11.4 million fish fatalities between 1963 and 1972. In 1971 about 77 percent (56.4 million) of the total reported fish kill occurred in the estuary-type water. The significant increase of fish kills in the estuaries since 1968 is of great national concern since estuaries serve as breeding and nursery ground for many species.

Monitoring data have so far been limited primarily to chlorinated hydrocarbons, because of their number, wide use, great persistence in the environment, and toxicity to certain wildlife and non-target organisms. At present, all of the different organochlorine insecticides have been reported from U.S. rivers and estuaries, sometimes in large quantities. Although these residues do not seem to present immediate danger to fish and shellfish, they were large enough to pose a threat to other elements of the estuarine ecosystem through recyling and magnification. Present monitoring data indicate that maximum pesticide residues can be correlated with proximity of monitoring stations to agricultural runoff.

Long-term sublethal effects of pesticides in estuaries are very difficult to assess at the present time, as most data on pesticide effects are limited to a few species and concentrations that are lethal in short-term tests under laboratory conditions. It is only, perhaps, in regard to the persistent organochlorine pesticides, DDT and dieldrin in particular, that more information is available concerning their behavior in the aquatic environment. It is now relatively easy to determine the concentration of a wide variety of organochlorine pesticide residues in estuarine and marine samples. It is, however, much more difficult to establish the significance of the residues either at the species or community level.

Health hazards to man arising from pesticide pollution in the estuarine environment have resulted from the persistence of pesticides in water, bioaccumulation in estuarine food chains, and some localized contamination of the coastal waters. Depending on the chemical nature of the pesticide and its biological behavior, the health hazard to man may be of an acute nature for people exposed locally or the result of chronic low level exposure of the general population from ingestion of contaminated food. Critical assessment of the ultimate health hazards of individual pesticides requires an adequate knowledge of their behavior in the estuarine ecosystem, their pathways through the dynamic system existing in the estuaries, and their fate in terms of accumulation or transformation. It is also necessary to have quantitative data for each of the various stages through which a pesticide passes before it finally comes in contact with the human organism. As in other areas of toxicological research, there is the added difficulty of extrapolating experimental studies in animals to man in order to measure the probable hazards to man.

Recent regulatory actions taken by the Environmental Protection Agency have placed a near total ban on domestic use of DDT, aldrin, dieldrin, heptachlor, and chlordane. Undoubtedly, for many years to come, these persistent chemicals will continue to be detectable in the estuarine environment due to seasonal flooding and the resuspension of estuarine sediments.

Pesticide pollution in the estuarine environment can be minimized through the use of alternative pesticides, more effective use of pesticides, removal of pesticides from water, improvement of farm management practices, and a better understanding of pesticide behavior in the estuarine ecosystem.

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THE IMPACT OF OFFSHORE PETROLEUM OPERATIONS ON MARINE AND ESTUARINE AREAS

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ABSTRACT

American is facing a serious energy crisis, as domestic petroleum supplies are consumed at a greater rate than new reserves can be located and placed in production. It is necessary to the nation's economic and political security to expand the search for crude oil and natural gas into the frontier areas of our Outer Continental Shelf. Expertise gained through more than two decades of exploration for and production of crude oil and natural gas in the Gulf of Mexico, and the advances in exploration, drilling and production technology and equipment, minimize the danger of environmental damage from offshore petroleum operations. Studies of the impact of oil on the marine and estuarine areas are continuing, and the results so far indicate that petroleum operations can be and are being conducted in an environmentally acceptable manner.

INTRODUCTION

A great deal of misunderstanding exists concerning the impact of petroleum operations on the biological, economic, and environmental sectors of the marine and estuarine areas. This misunderstanding, in turn, has led to public concern, particularly in light of proposed expansion of offshore petroleum industry activities following the energy crisis.

It would be naive—and inaccurate—to suggest that a significant expansion of exploratory, production, transportation, and refining activities would be without some impact on shore and near-shore life. But it would be equally naive—and inaccurate—to suggest that such impact as would occur would be all negative, or that any impact, per se, would be intolerable from an environmental point of view.

There is clearly an urgent need to not only protect and sustain the viability of our estuaries, but to develop secure domestic petroleum reserves as well. Our economic and political structure was visibly shaken by the 5-month embargo of Arab crude oil and products refined overseas from Arab crude, and by the fourfold increase in the cost of imported oil imposed by the Organization of Petroleum Exporting Countries.

THE NATION'S ENERGY MIX

Petroleum, that is, crude oil and natural gas, provides this nation with 77 percent of its current energy requirements. Crude oil supplies 46 percent; natural gas, 31 percent. Our heavy dependence on petroleum is the product of many factors, not the least of which have been—and continue to be—environmental considerations.

In the case of coal, which currently provides 18 percent of the energy market, environmental restrictions have played a major role in limiting production. Bans or severe restrictions on the use of the more economical mining methods, as well as sulfur emission control standards—some of which go far beyond the need to protect national health and safety—have greatly hampered moves to increase coal production and use. This has been an important factor in increasing demand for petroleum, as an alternate fuel in manufacturing and electrical power generation.

Further demand has been placed on petroleum by the seemingly interminable delays in trying to site and construct nuclear power generating plants, and in allowing onstream operations of existing facilities. While technological problems have caused some of these delays, environmental considerations were at the base of many delays—and, in some cases, cancellations—of nuclear plant construction. Thus, despite the rosy future predicted for power from nuclear reactors during the 1950's and '60's, less than 2 percent of U.S. energy is now derived from nuclear generators.

A similar fate has befallen potential hydroelectric power plant construction. Virtually every attempt to develop a new hydroelectric power site is blocked by environmental opposition. The few remaining

sites for hydropower installations have—for all practical purposes—been ruled out of consideration by environmental activities.

Thus, we have been left with a growing dependence on oil and natural gas as the suppliers—at least for the next 10 to 15 years—of our nation's energy. Continued reliance on potentially insecure and high cost foreign oil, however, is not a practical solution to our energy problems. The economic consequences of over-dependence on imports—both from a security and balance of payments aspect—should have been indelibly engraved on the public conscience in the aftermath of Winter 1973–74 and in the outflow of U.S. dollars in 1974.

Yet, if we are to keep even our present level of productivity—much less increase our industrial activities to meet the needs of an economic upswing—U.S. imports of crude and refined oils must temporarily continue. There is no viable alternative, just as there is no viable alternative to increasing our domestic exploration and production activities. Only increased availability of petroleum will permit the nation to buy the time needed to develop alternate energy sources.

There is, on the horizon, the vision of a number of self-renewing, non-polluting energy sources. These include—but are not limited to—ocean, tidal and wind power, geothermal energy, nuclear fission, and solar power. Prototype facilities and/or laboratory models exist for some of these energy alternatives. But it will be a number of years—perhaps into the next century—before they become economically feasible. Time, however, is the critical factor. For all practical purposes, petroleum is the only major energy source with the proven technology capable of producing sufficient fuel to tide this nation over until alternate energy sources become reality.

The United States Geological Survey estimates that the remaining total petroleum resources of the United States, discoverable and recoverable under today's technology and economics, may range as high as 189 billion barrels of oil and 1,094 trillion cubic feet of natural gas. The onshore potential, however, appears less readily recoverable than the potential of the Outer Continental Shelf (OCS). The larger, more readily located onshore areas are believed to have been found and placed into production. The primary locations for additional onshore resources are thought to lie at greater depths and in undeveloped hostile areas. Thus, the need to search out the oil and natural gas deposits of the OCS assumes greater importance.

OFFSHORE PETROLEUM EXPLORATION AND PRODUCTION

The United States Geological Survey has estimated that the discoverable, recoverable petroleum resources of the OCS may range from 10 billion to 49 billion barrels of crude oil and 42 trillion to 181 trillion cubic feet of natural gas. By geographic area, these deposits are thought to be within the following estimated probability range:

Offshore Area	*Crude oil (in billions of barrels)*	*Natural gas (in trillions of cubic feet)*
Atlantic	2–4	5–14
Gulf of Mexico	3–8	18–91
Pacific	2–5	2–6
Alaska	3–31	8–80

Development of this potential becomes all the more expedient in light of the almost steady decline in the ratio of U.S. proved reserves to production, stemming, for the most part, from governmental interference in the fuels marketplace. U.S. domestic production peaked in the early 1970's. And it will be several years before that situation begins to be reversed by the flow of oil from Alaska's north slope, increased production through secondary and tertiary recovery methods, and new production from existing, but not fully developed, fields. Nevertheless, the master key to petroleum security rests firmly in unlocking the as yet undiscovered potential of our Outer Continental Shelf.

Petroleum exploration and production from marine areas is not an experimental undertaking. As far back as the late 1890's, underwater drilling was a fact of life in California, where piers were extended into the water to support drilling and production facilities. However, modern drilling and safety technology had its origin in petroleum operations in the Gulf of Mexico, with drilling starting in earnest following World War II.

To date, more than 19,000 wells have been drilled in the U.S. marine environment. And, in fact, nearly 17 percent of all domestic oil and 19.5 percent of our natural gas production in the U.S., today, comes from offshore activities.

Yet, despite the headlines which would indicate otherwise, there have been only four significant oil spills from drilling and production operations in our offshore areas. And none, not even the much-publicized spill in the Santa Barbara Channel in 1969, caused permanent ecological damage.

Since that spill, marine exploratory and produc-

tion technology has improved greatly. Both industry and governmental specifications have undergone significant upgrading to decrease oil spill potential. Safety equipment, monitoring techniques, and personnel training in spill prevention and cleanup have advanced. The capability of the industry to minimize environmental damage has been substantially enhanced.

EFFECTS OF OIL ON MARINE BIOTA

Quite frankly, prior to the Torrey Canyon accident off the Cornwall Coast of England, and the Santa Barbara spill about two years later, there had been little investigation of the fate of oil in the environment. Such is no longer the case. While much is yet to be learned in this area, a number of facts have evolved from existing research.

In May 1969, a series of studies—part of a multimillion dollar research program—was initiated by the American Petroleum Institute. These studies were designed to develop scientific answers to questions surrounding the fate of oil in the marine environment and its biological impact. The studies have been and are being conducted by some of the nation's leading universities and independent research laboratories. Research contracts have been awarded to such institutions as the University of Southern California, University of Maryland, Texas A & M University, Scripps and Woods Hole Institutions of Oceanography, Battelle Northwest and Battelle Columbus Laboratories, Exxon Research and Engineering, and the Bermuda Biological Station.

The petroleum industry, through the API program, wanted to find out, for example, answers to these questions: What happens to oil in the sea; how much is evaporated, goes into solution, is physically dispersed; what are the mechanisms that brought about these changes; and what are the effects of climatic, oceanographic, meteorological, and chemical influences on oil in the sea.

The studies sought answers to biodegradation processes and how they vary as a function of climate, bacterial composition and distribution, nutrient uptake, and seasonal variation. The effects of oil on the food chain have been studied, including the impact on organisms at the egg, larvae, juvenile, and adult stages, and on their subsequent generations. Questions as to the effect of dispersants superimposed on an oil-polluted biosystem have been considered. Bioassay data on No. 2 fuel oil, various crude oils, and residual fuel oil were sought, including the retention, concentration, and depuration of such oils by marine organisms. Finally, the industry wanted to determine the immediate and long-term effects of an oil spill, and how this differs from chronic oil pollution sustained by persistent natural seepage.

At this early date, all of the results of this ambitious research program are not in. However, the facts that have evolved—coupled with other investigations throughout the world—confirm certain data and put to rest certain myths and speculations. These known facts are:

1) The fate of oil and its immediate and long-term impact depend upon a highly complex interrelationship of physical, chemical, and biological factors. These include evaporation, dispersion, flushing, dissolution, photo oxidation, littoral deposition, sedimentation, accumulation, microbial oxidation, and last, but most important, organism uptake. In the majority of spills, winds, currents, and tides rapidly dilute or disperse the oil below toxic concentrations.

2) Oil is ingested by marine organisms, such as shellfish, shrimp, and finfish. The effects depend on the particular species, its stage of growth, and the amount and kind of oil ingested. Recent uptake and depuration studies have been conducted by the Battelle Northwest Laboratories in Puget Sound, at the Texas A & M Marine Research Laboratory in Galveston, and at the Scripps Institution of Oceanography in California. Admittedly, laboratory studies have their limitations when it comes to predicting the effects of oil on organisms in the real world. Nevertheless, the results of such studies have confirmed that marine organisms do accumulate petroleum hydrocarbons, but once placed in an oil-free environment, the organism quickly discharges the ingested oil. For example:

(a) At Texas A & M, brine shrimp were found to absorb and purge aromatic hydrocarbons in a matter of hours. No metabolization of the oil fractions occurred.

(b) At Scripps, however, three different species of fish were found to detoxify these hydrocarbons by metabolizing them in the liver and excreting the byproducts in their urine.

(c) At the Battelle Northwest Laboratories, Pacific oysters that had assimilated oil were found to depurate the hydrocarbons within a few days when returned to an oil-free environment.

(d) In the Plymouth Laboratory in England, the spider crab *Maia squinado* was found to rapidly detoxify and excrete naphthalene.

3) Biological damage to an ecosystem depends upon such factors as: the type of oil spilled, biota

of the area, the dose of oil, the physiography of the area, the season, weather conditions, previous exposure of the area to oil, exposure to other pollutants, and treatment of the spill.

4) Three conditions must prevail for damage to occur from a spill: (a) a refined oil must be involved; (b) the volume of oil spilled needs to be large with respect to the receiving body of water; and (c) storms or heavy surf must thoroughly mix the water, oil and sediments in the area.

5) Crude oil constituents, especially the volatile aromatics—naphthalenes and olefins—which have a low boiling point, are far more toxic than are the remainder, and are more soluble in water. Fortunately, these lighter constituents quickly evaporate, so that the risk is a short-term one.

6) Certain polynuclear aromatics, such as 3,4 benzpyrene, are potential carcinogens. Some of them occur in crude oil in minute quantities. It has been postulated that these carcinogenic polynuclear aromatics are assimilated by marine organisms and are concentrated as they are passed up through the food chain to man. There is no evidence, however, that abnormal growths, either tumors or cancers, in man or marine organisms result from oil spilled in the marine environment and subsequently transferred through the food chain. Another team of scientists, who did their research on the Sargasso Sea ecosystem, found that petroleum hydrocarbon concentrations were essentially constant throughout the food chain. Polynuclear aromatics, incidentally, are produced by vegetation and phytoplankton in large quantities, and are, moreover, biodegradable.

7) Refined oil, such as No. 2 fuel oil, is generally more toxic than crude oil. When massive amounts of such oil inundate coastal areas for sustained periods of time, extensive damage to marine fauna can occur and complete restoration may take years. Fortunately, such episodic spills are rare.

8) No spill, not even the most severe (e.g. Torrey Canyon, West Falmouth, and the Tampico Maru), has resulted in any permanent damage to the environment. In most spills, biological recovery is achieved within a few generations, involving less than one year.

9) Only about 20 percent of the more than 100 spills classified as "major," that occurred between 1960 and 1971, resulted in sizeable seabird mortality. According to one study, for other forms of marine life, damage was described as extensive in approximately 15 percent of the spills. In several of the spills, damage to marine life was caused by the misuse of highly toxic dispersants. Such dispersants have now been largely replaced by nontoxic substitutes.

10) Low levels (10–100 ppm) of oil dispersant emulsions can, under laboratory conditions, reduce primary productivity of marine phytoplankton and its production of chlorophyll *a*. Oil dispersant emulsions at a level of less than 1 ppm, however, have a stimulatory effect on the phytoplankton resulting in an increase in the mean productivity rate.

At such low concentrations, oil is a nutrient—a source of carbon. When flagellates are exposed to highly toxic water-soluble oil concentrations for 24 hours, their growth rate and production of chlorophyll *a* is virtually stopped. When transferred to a fresh medium, they resume normal growth rates (1 to 1½ generations each 24 hours) and chlorophyll *a* production within three to four days. Only a relatively small number of flagellates need to survive to repopulate rapidly a given area after a spill.

11) Salt marsh grasses, when exposed to oil, will recover very quickly, especially if no detergent treatment is undertaken and repeated oilings do not occur.

12) With rare exceptions, oil spills do not cause death to free swimming finfish. Such fish evidently sense the presence of oil and swim clear of the slick. However, fish that swim near the surface, such as pipe fish and capelin, would be most susceptible; those found at intermediate depths, such as shiner perch, would be less susceptible; and those inhabiting the water column near the bottom, such as flounder and sculpin, would be least susceptible.

13) In general, an organism is more susceptible to oil at the larval stage than at the juvenile stage; and the juvenile stage is more vulnerable than the adult stage. There is always an exception to the rule. It is found that the least susceptible stage for brown shrimp is the post-larval period of life.

14) Chronic and acute exposures to oil in laboratory tests have not resulted in any growth inhibition in brown shrimp or oysters.

15) The health of a marine community in the immediate vicinity of a natural oil seep was comparable to the health of a similar (control) community far removed from seepage areas.

These, then, are some of the facts that are surfacing from studies of the impact of oil on the marine environment. Many more questions and myths remain to be clarified. They will require thorough and dispassionate studies. Such work is ongoing, not only by the oil industry and the federal government, but by state and private laboratories throughout the world.

OFFSHORE OIL SPILLS STUDIES

The widely circulated charges of massive and permanent damage to nearshore and estuarine life re-

sulting from petroleum exploration, drilling, and production operations offshore have, to a large extent, been generated out of fear of the unknown, and nurtured by non-factual information from a host of instant experts on the effects of spilled oil. This was made particularly clear at the time of the Santa Barbara spill. And, unfortunately, the disproved charges are still repeated from time to time in the media.

The facts concerning the damage from that spill are readily available, the results of two independent scientific studies of the area. The first, by the Allan Hancock Foundation of the University of Southern California, noted that, while there was some loss of life among certain species of the Channel's flora and fauna attributable to the spill, other factors present in the area at the time of the spill contributed significantly to the mortality rate. Among these contributing factors were:

- For centuries, crude oil has been entering the Santa Barbara Channel from natural seeps (natural seeps off Coal Oil Point, for example, exude from 11 to 160 barrels of crude oil daily into the sea);
- In winter (as when this particular spill occurred) marine life in the channel is at a low ebb—a seasonal factor unrelated to pollution; and
- The worst floods in 40 years had taken place just prior to the spill, placing sealife under extraordinary stress from freshwater runoff, storm debris, sewage, sediment, and pesticides.

The Allan Hancock Foundation study, based on on-site observations and comparisons to pre-spill data, found that, of the 18,000 birds in the channel at the time of the January 1969 spill, 3,500 to 4,000 birds died from all causes. By May, seasonal migration had brought the bird population up to 85,000. Only isolated traces of oil remained buried on the beaches a year after the spill. Damage to the biota was not widespread, but was limited to several species; and the area has recovered well. The channel fish catch was actually found to have increased in a 6-month period following the oil spill, compared to the year-earlier period. Despite the claims of some people at the time of the spill, the incident had no apparent effect on whales and seals.

Commenting on the Santa Barbara spill, a scientist at the California Institute of Technology (which was not a party to the 40-man investigation by the Allan Hancock Foundation) concluded, "There is one unavoidable fact—all animals are reproducing now in the Santa Barbara area."

While marine operations have been undertaken over a longer period of time in the California offshore area, operations in the Gulf of Mexico have been significantly greater, both in exploration and production. More than 16,000 oil and gas wells have been drilled in Gulf of Mexico waters . . . without damage to the fish population.

The commercial fish catch in the gulf increased from 571 million pounds in 1950 to 1.5 billion pounds in 1973, according to the U.S. Department of Commerce's National Marine Fisheries Service, while the value of the commercial fish catch rose from $50.4 million to $268 million—an increase of 432 percent. During the same period, the percentage of the total commercial fish catch in the U.S. taken from the Gulf of Mexico rose from 12 to 33 percent. Most of this increase is attributable to improved fishing techniques and the taking of menhaden (a formerly non-commercial fish). However, the increase does indicate that petroleum operations in the area have not decreased the commercial fish population.

Sport fishing has actually improved in the area of the oil platforms. The platforms provide a foundation for the growth of sea plants and invertebrates, thereby creating the first step in the food chain. About a dozen or more species of fish virtually unknown in the area prior to drilling operations have been recorded near the rigs. Many of these fish are believed to have been brought to the installations by ocean currents as eggs or fry, and remained to mature under the favorable food and cover conditions created by the platforms.

Shrimp landings from the Gulf of Mexico, in 1973, accounted for almost one-half of the total U.S. shrimp catch (182.1 million pounds out of the 372.2 million pound total), and for 79 percent of the total value of the U.S. shrimp catch. And the National Marine Fisheries Service reported marked production increases in hard blue crabs taken from the gulf in 1973.

In reference to the effects of oil spills from marine platforms in the gulf, Dr. John G. Mackin, professor emeritus of biology, Texas A & M University, has concluded that they have had little harmful effect on the area's marine life. Dr. Mackin has studied the inshore and nearshore Gulf of Mexico ecology and marine communities extensively since 1947. His view is supported by Dr. Lyle St. Amant, assistant director, Louisiana Wildlife and Fisheries Commission, who stated recently—in connection with marine operations in Louisiana gulf waters: "We cannot detect any harmful effects on fish."

In-depth studies of the effect of petroleum offshore operations, over an extended period of time, can and do provide vital information on changes in the marine community. Too often, however, other information is presented which lacks the necessary foundation for accurate conclusions. Baseline stud-

ies, which fail to extend through a continuum of seasons and fail to cover a number of cycles, frequently result in questionable data. For example, a baseline study provides a reference point for a particular area at a particular time. A second baseline study taken later—without the benefit of a continuous history of environmental events—would provide a similar reference point for its area and point of time. The interstitial, unrecorded events, however, could so distort the differences as to make comparisons of little value.

A temporary gyre moving through the water column—or a number of other ephemeral events—could significantly alter the benthic marine community, perhaps leaving a permanent change in the biota of the area. If unrecorded for want of the baseline continuum, the conclusions drawn from the change in the benthic community might easily—and erroneously—be assigned to other causes, for example, a later recorded oil spill, invalidating the results of the more recent baseline study.

PREVENTION AND CONTROL OF OIL SPILLS

The petroleum industry has expended a great deal of effort, time, and money on oil spill prevention through employee training courses and sound maintenance programs. Even with these continuing efforts, some risks remain. Accordingly, the industry has also taken the initiative in developing the means to minimize spills that do occur.

The harbor cooperative has been one of the results of industry efforts to increase response capability. The form of these cooperatives varies with the needs and location; the object, however, is to pool the funds and/or equipment of companies in a given area, thus significantly increasing their response capability. In some cases, these cooperatives include municipal fire departments, and other local governmental agencies.

There are in existence, or in the planning stage, some 100 harbor cooperatives in the United States. They are located not only on the gulf, east and west coasts, but also on inland lakes and rivers. These include several basic forms of cooperatives: industrywide (oil companies in the area); communitywide (oil companies, other companies, government agencies, and public organizations in an area); and subscription (an experienced local contractor supplying cleanup equipment, materials and key manpower).

For example, one such cooperative—funded by the oil companies searching for energy resources in the Gulf of Mexico—employs a contractor to store and maintain both shallow-water and open-sea equipment in a state of 24-hour readiness.

Included are helicopters, skimmers, booms, communications systems, bird rescue and cleaning materials, and sorbent generating equipment. All can be easily transported by air, land, or water. Fast response equipment is also stored at several strategic locations, enabling on-the-scene activities to begin at a spill as far as 100 miles distant, within 12 hours.

Oil spill cleanup cooperatives have demonstrated their ability to respond promptly and effectively in sheltered waters or in open seas under relatively calm conditions. However, technology for handling spills under heavy sea conditions needs to be further developed. The petroleum industry is committed to expanding its cleanup skills to meet needs wherever they arise, and is continuing its efforts to advance the state of the art through research and experimentation.

Among the projects under study or in developmental process are these: establishing and updating compendiums cataloging information on available sorbents, surfactants, combustion promoters, sinking agents, and biological agents; developing and testing an open-sea oil skimmer; researching methods for protecting shorelines and beaches exposed to oil from spills, using petroleum-consuming microorganisms and polymeric films; and improving training of personnel in the use of techniques and equipment for oil spill cleanup.

Work is also continuing to improve avian protection techniques. Experiments are under way on methods to frighten sea birds away from spill areas, using distress cries and other sonic techniques. And substantial progress has been made in the area of improved rescue and treatment of oiled waterfowl.

The industry feels that the best way to handle oil spills is to prevent their occurrence. To this end, a sophisticated array of hardware and practices has been developed. An indication of the extent of spill prevention techniques and equipment can be found in the following description, although the material mentioned is by no means all-inclusive.

At the well, where prevention begins, automatic shutdown devices are installed as part of the offshore drilling and production program. These devices detect increases and drops in pressure, changes in flow rates, and other production factors. Subsurface valves, for example, close down the flow of oil in event of an accident, malfunction, or other incident at the surface. Master switches are installed which can stop the entire production system, should an emergency threaten life, property, or the environment. Fire detection devices can trigger the emergency

shutdown system. For day-to-day operations, drainage and containment systems collect any spillage or waste oil. Other safety devices in common use on marine platforms include navigational aids to warn vessels.

The platforms, themselves, are designed to withstand storms equivalent in intensity to that of the worst storm recorded during a 25- or 100-year period, depending on location. When storms of sufficient intensity to affect drilling occur, all operations cease, and the drilling platform is secured. If the storm is expected to be especially severe, personnel are removed from the platform.

Other measures are taken during daily operations to prevent pollution from petroleum activities. These include the onboard processing of water from wells to remove oils, or the transportation of these liquids to shore for separation processing.

When an oil reservoir is depleted, the wells are plugged with cement to protect underground strata, and to prevent any leakage to the surface. Equipment is removed, and underwater piping is cut off below or at the seafloor, to eliminate any hazard to commercial fishing.

Pipelines play a major role in transporting oil and gas produced offshore to onshore facilities. There is little reason to anticipate increased pollution from this source, because pipelines are constructed to safety standards set forth in strict industry codes and, in the United States, in government regulations. These standards include specifications for design, construction, operation, and maintenance. They make provision for automatic safety alarm systems, shutdown devices, and regular inspections along the lines to check for possible leakage, damaged piping or construction; and, inland, for any watercourse changes that might affect pipe security. The record in oil pipelining has shown it to be the safest and most secure mode of transporting oil.

ONSHORE IMPACTS

A concern closely related to the need for an acceptable environment is the question of onshore development resulting from offshore production of petroleum. The social, environmental, and economic impacts of existing offshore and nearshore production in the Gulf of Mexico and the Santa Barbara area, unfortunately, cannot be used as an accurate gauge of impacts that might be anticipated in the areas adjacent to potential frontier Outer Continental Shelf areas, such as the Atlantic coast. In the Gulf of Mexico, for example, onshore petroleum production development started a number of years before any attempt was made to develop the offshore potential. The first year of recorded petroleum production in the State of Louisiana was 1902, and for Texas, 1889. While drilling in the estuarine areas of Louisiana began in the 1930's, offshore exploration and development began in the late 1940's, with significant activities continuing since that time.

However, several sound projections can be made concerning the impact of petroleum operations along the east coast. First, advancements in the state of the art of petroleum offshore operations will minimize any environmental risks that might be associated with such activities. Additionally, there are in effect today in the United States stringent environmental laws, regulations, and controls that will prevent the construction of environmentally unacceptable support facilities.

Second, the social and economic aspects of Atlantic coast offshore and onshore support operations will be minimized by the nature of the areas nearest the most likely exploration and production activities. Unlike the gulf coast region during the early years of petroleum operations there, industrial complexes already exist along the east coast, for example, the Newport News-Norfolk, Philadelphia-Baltimore, and Greater Metropolitan New York areas. This industry is well-suited to provide many of the requirements anticipated in implementing any Atlantic offshore programs.

Local helicopter services, water transport, shipyards, and other businesses would logically be called upon to provide much of the materials and support needed offshore. And, certainly, the impact on local payrolls, work orders, and employment opportunities would be beneficial. At the same time, roads, schools, and public services are presently in place, significantly lessening any negative impact on government finances from offshore exploratory and development operations.

COASTAL ZONE MANAGEMENT PLANNING

It takes from three to 10 years to bring a new oil or gas field into full production, once petroleum is discovered, if the search turns up commercially significant quantities of petroleum. Add to this time the years required to develop leasing schedules, hold environmental impact hearings and draw up impact statements, hold lease sales and conduct exploration activities, and the time before significant impact could occur is placed into proper perspective.

That time could—and should—be used to develop the coastal zone management plans that would en-

able orderly and environmentally acceptable support facilities to be built. And that time would also allow for the programming of any governmental services that might be required over the productive life of the reservoirs. Thus, environmental, social, and economic impacts could be anticipated and intelligently accommodated within a logical time frame.

SUMMARY

There is a critical need to develop energy resources in the United States, resources that will protect the political, social, economic, environmental, and military security of the nation. Petroleum—crude oil and natural gas—will be called upon to provide the lion's share of that energy security until alternate energy sources can be developed.

This nation and its people cannot afford the luxury of waiting until our known supplies are exhausted, in the blind faith that new sources will be provided. Rather, we must pursue—in an orderly and expeditious manner—the development of our petroleum potential. The technology exists for such development. And those potential sources of oil and gas can be located and produced with minimal impact on the environment.

While studies continue to evolve even safer methods of petroleum production, and while new energy sources are being researched and developed, we must proceed in the search for secure domestic petroleum reserves. That means opening up new areas to development—both offshore and in the more remote areas, such as onshore Alaska—on a timely basis designed to accommodate the petroleum industry's capability to safely explore and develop leased areas. There is no other viable alternative to such development, if we are to reduce dependence on imported crude oil and refined products.

RESEARCH APPLICATIONS

THE EFFECT OF ESTUARINE CIRCULATION ON POLLUTION DISPERSAL

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ABSTRACT

This paper gives a brief review of different types of circulation in estuaries, how they act to disperse pollutants, and to what extent the dispersion process can be modeled by existing analytical, numerical, and hydraulic models.

INTRODUCTION

One important feature of estuaries is their ability to assimilate wastes and transport them to the ocean. It is possible, by adequate mixing with the receiving water, to discharge a larger quantity of waste into an estuary than into the rivers that feed it, while still meeting a given receiving water standard, because in addition to the inflow of river water the estuary contains a continuous circulation of water from the ocean to help with dilution. Pollution in an estuary, or more precisely the concentrations of undesirable materials, depends on two things: the quantity and makeup of the waste discharges, and the rate of flushing. In general, the flushing rate increases towards the ocean end. At the landward end the only flow available for flushing is that of upland rivers, but the closer one approaches the ocean the more recirculated ocean water is available to increase the flushing rate and decrease the concentration of wastes. Temperature, also, is affected by the flushing rate; except, close to the source discharges of warm or cold water are diluted in the same way as other wastes.

This paper discusses how flushing rates can be quantified, predicted, and used as part of the process of specifying allowable waste loadings. First, in section II, we discuss the various mechanisms which, in concert, drive the circulation of ocean water. Section III describes a practical analysis for computing flushing rates, while section IV describes procedures that can be used in a more predictive way, but are still in a state of research and development. Section V discusses both practical needs relevant to current legislation and longer-term research needs.

TYPES OF CIRCULATION

The flushing of estuaries results from three influences: the ebb and flood of the tide, the wind stress, and the higher density of ocean water relative to river water. Some estuaries are influenced equally by the three factors, some by only one or two. Which factors are important controls how the estuary flushes its pollutants, and, perhaps more importantly, determines the effect of such projects as dredging, harbor extension, and the like. This section describes five types of circulation. The first, gravitational circulation, results from the relative heaviness of ocean water; the second, third, and fourth are three different mechanisms caused by the tide; and the fifth is circulations driven by wind.

Gravitational Circulation

Gravitational circulation is so called because it results from gravity pushing heavier ocean water landwards up the bottom of the estuary. Figure 1 is a simplified profile sketch of a purely gravitational circulation; in three dimensions the circulation is landward along the bottom of the deeper channels, upward and transversely across the cross section, and returning seaward mixed with freshwater in the surface layers. This type of circulation has received a great deal of analytical, laboratory, and field study; Fischer (1976) discusses the results of approximately 20 previous reports.

Where there is little tide, as in the Gulf of Mexico, there may be little mixing between the ocean and freshwater; the ocean intrudes as a wedge and the freshwater rides over the ocean water. This situation occurs frequently at the mouth of the Mississippi. Similarly, in the Alaskan fjords the freshwater

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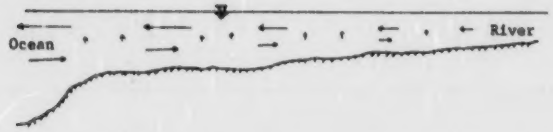

FIGURE 1.—A typical pattern of gravitational circulation in a partially stratified east coast estuary.

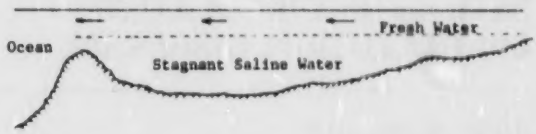

FIGURE 2.—Outflow of a layer of fresh river water over stagnant saline water; this flow pattern is typical of fjords.

overrides the salt and reaches the ocean almost without dilution (see Figure 2). In these cases the dispersal of a pollutant depends crucially on whether it goes into the upper, freshwater, or the lower, saline water. In fjords, the flushing time of the salt water may be on the order of years, while the fresh layer may traverse the fjord in a few days or at most weeks. It is particularly important that design procedures be used to make sure that pollutants are not trapped in the slowly circulating lower level.

Conversely, along the east coast most estuaries are either partially or well mixed; the difference in salinity between upper and lower layers in Chesapeake Bay, for instance, is usually on order of 15 percent of the difference between ocean and fresh water. In these estuaries it does not matter so much where the waste is discharged as turbulent mixing will distribute the waste over the cross section.

Tidal Pumping

"Pumping" is a term used to describe circulations induced by the ebb and flood of the tide. The tide usually flows in more strongly in some channels and out more strongly in others as though a pump were pushing the water around. Sometimes sailors of small boats know more about these currents than do engineers, but they are very important in flushing pollutants. Pumped currents can be simulated by numerical programs; for instance Figure 3, taken from a report by the California Department of Water Resources (Nelson and Lerseth, 1972), shows a computed pumped circulation in San Francisco Bay. Note, for instance, the circulatory current in San Pablo Bay (between Vallejo and San Rafael) having a predicted magnitude of approximately 10,000 cfs. This is about five times the combined inflow of the Sacramento and San Joaquin Rivers.

Chopping

"Chopping" is a term sometimes used to describe the detention of a pollutant by side embayments, shoals, and the like. This mechanism is also very important in the spread of pollutants, because of the typical sequence of events shown in Figure 4. In 4a a cloud of pollutant is being carried landward by a flooding tide. In 4b part of the cloud is detained in a side embayment, which is being filled by the flood. In 4c the water surface has begun to drop and the embayment is emptying back into the channel. Because of the hydrodynamics of tidal flows the current in the channel does not slack until after high or low tide, with the result that shoreline irregularities spread out a cloud of pollutant somewhat as shown in the figure.

The Shear Effect

The shear effect is an additional spreading mechanism which takes place in any flow, tidal or not. It results from the faster flow velocities found at the center and surface of the cross section, as compared to the slower velocities near the bottom and shores. Turbulent mixing spreads a pollutant across the cross section, and then the difference in longitudinal velocities spreads the pollutant up and down the channel. In rivers this mechanism is primarily responsible for longitudinal dispersion, but in estuaries the other mechanisms usually seem to be more important.

Wind-driven Circulation

The visible effects of wind are white caps and violent turbulence where waves break near shore. Impressive as they may be, they usually have little to do with pollutant dispersal, being limited in scale and unable to accomplish long distance transport. Wind does play an important role in some estuaries, however, because it can drive large scale horizontal circulation. In a large open bay a constant wind will push water in the wind direction across shallows and at the surface, while a return flow will be found underneath in the deeper section. Figure 5 shows such a circulation around an island in a bay which is deeper on one side of the island than on the other; the circulation goes with the wind on the shallow side, and against it on the deeper side. This sort of circulation has the same effect as tidal pumping; it is as though a large pump is pushing the water around and dispersing the pollutant.

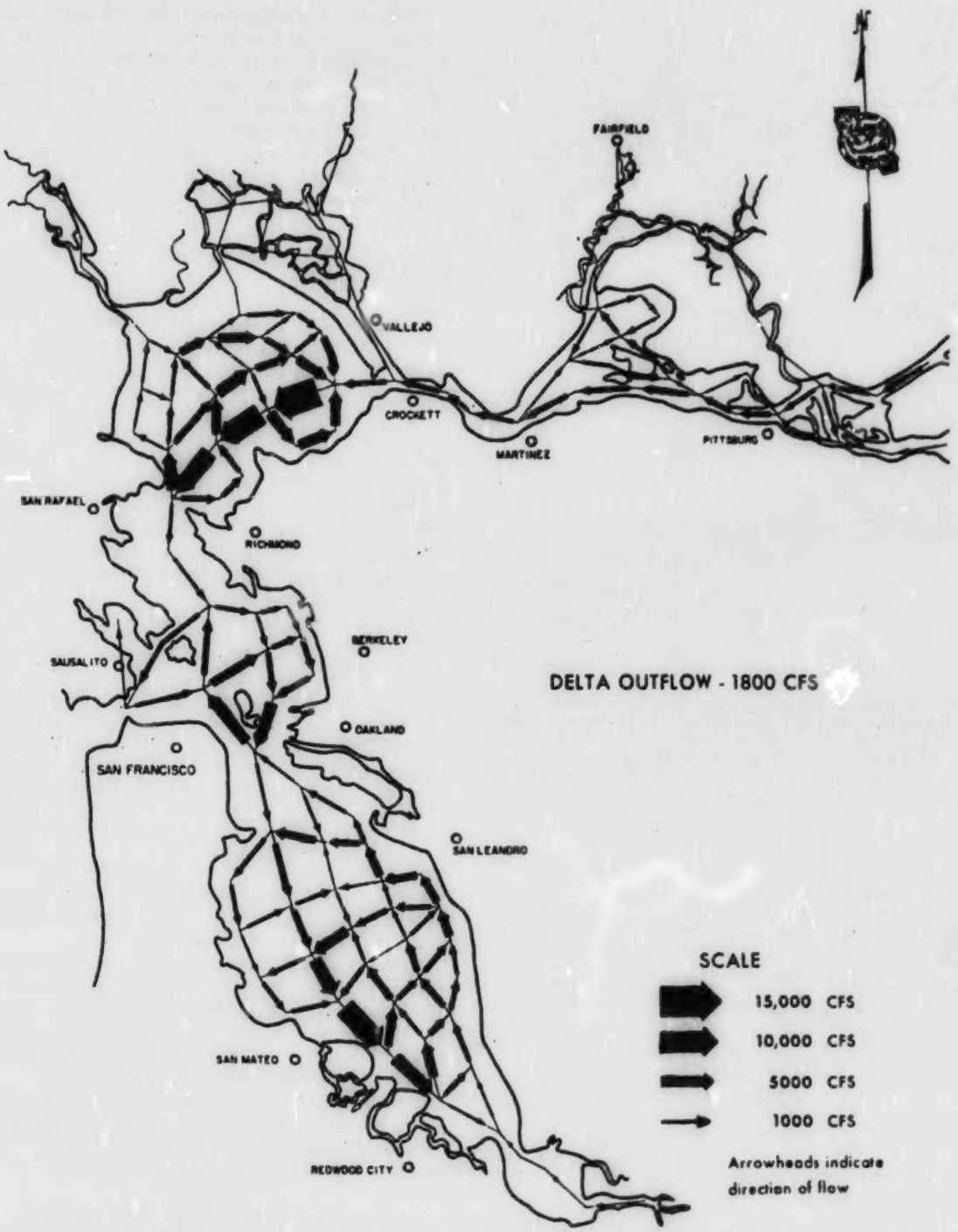

FIGURE 3.—Circulation due to tidal "pumping" in San Francisco Bay. This circulation pattern was obtained by a computer program, and is taken from a report by Nelson and Lerseth to the California Water Resources Control Board.

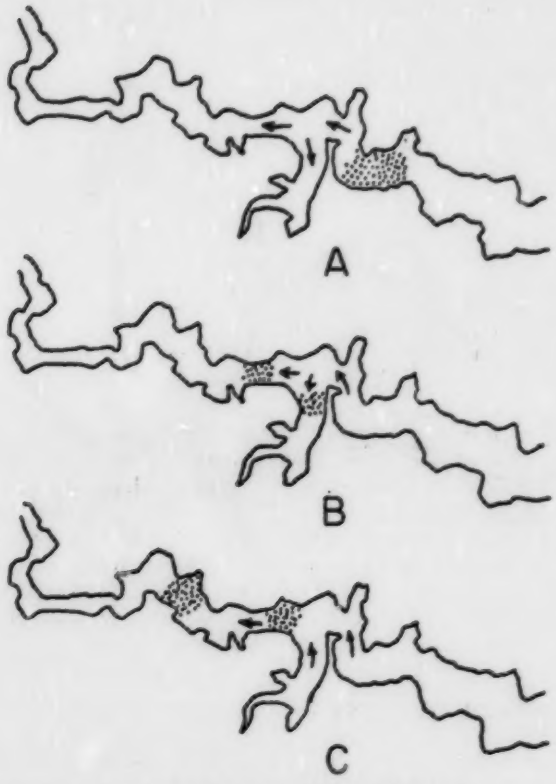

FIGURE 4.—An example of the "chopping" mechanism for dispersing a pollutant. The side embayment acts as a storing basin which fills and empties out of phase with the flow in the main channel. A portion of the cloud of pollutant is detained by the embayment and subsequently reinserted into the channel some distance from the rest of the cloud.

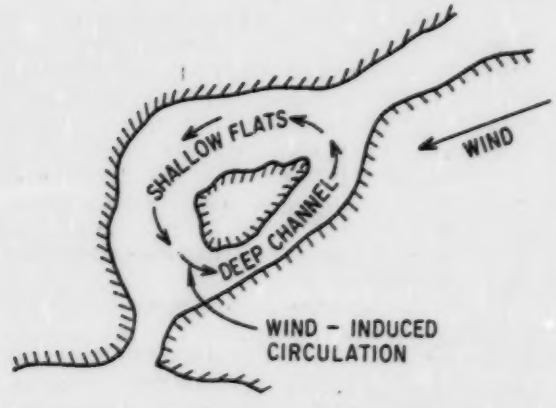

FIGURE 5.—An example of a circulation driven by a steady wind. The effect is similar to that of tidal "pumping," although the cause is different.

Each of the mechanisms described above exists to some extent in almost every estuary. In concert, the circulations result in a "flushing discharge" which can be used to compute pollutant concentrations. Each mechanism can be analyzed, but with varying degrees of accuracy and by different means. In section IV we discuss several analytical techniques and mention which is suitable for analyzing which mechanism.

EFFECTS OF CIRCULATION ON DISPERSAL

The combined effect of the various circulations is to greatly increase the assimilative capacity of an estuary by providing an effective flow much greater than the flow of the rivers which feed the estuary. This effective flow is the flow relevant to pollutant concentration computations, and is the flow that should be used for regulatory purposes. In the saline portions of existent estuaries one can compute the effective flushing discharge by a simple procedure. All one does is to measure the average salinity near an outfall; then, to a good approximation, the effective discharge is computed by the formula

$$Q_d = Q_f\left[\frac{S_0}{S_0 - S}\right] \qquad (1)$$

where S_0 is the ocean salinity, S the salinity near the outfall, and Q_f is the inflow from upstream rivers. The concentration of a pollutant discharged in the vicinity of the outfall, is given by a mass-balance computation using the effective discharge.

$$C = C_0[Q/Q_d] \qquad (2)$$

C_0 and Q are the concentration and flow from the outfall, and Q_d is the result obtained from equation (1) at the location of the outfall.

Concentrations upstream and downstream of the discharge point decrease from the peak near the discharge. A complete description of the analysis, for a non-conservative pollutant, was given more than 20 years ago by Stommel (1953). One important result is that moving an outfall nearer to the ocean does not decrease the concentrations of conservative pollutants in the estuary seaward of the outfall; it does, however, decrease the peak concentration and the concentrations landward of the outfall.

Stommel's analysis does have some serious limitations. First, it can only be used with an existing salinity distribution. It is of no use at all to predict

changes in concentrations because of construction projects. Second, the analysis assumes steady state; the pollutant must be discharged at a constant rate, and the inflow from upstream rivers must be constant. Neither of these conditions is often seen in practice. Third, the analysis assumes complete and instantaneous mixing of the pollutant across the cross section, and a uniform salinity across the cross section. In practice, mixing within a cross section may take considerable time; for instance, a recent dye experiment in a section of the Delaware Estuary, where the estuary is about 1 mile wide, showed that the cross sectional mixing time was approximately 10 days (see Fischer, 1974). If mixing is not complete equation 2 gives a concentration that can be much too low; higher concentrations will be found in the vicinity of the outfall.

Concentrations near outfalls, and cross-sectional mixing times, may be predicted in several ways. Immediate diffusion of an effluent from a pipe may usually be analyzed as a problem of mixing of a buoyant jet. This subject has been studied in considerable detail, as described in a recent review paper by Koh and Brooks (1975). In the zone close to the outfall where mixing is controlled by the method of discharge, it is a straightforward matter to predict the dilution within the jet. This zone is usually small, however, and there is a substantial mid-field zone in which the concentration disperses as a plume, and mixing is primarily due to the turbulence in the receiving water. Figure 6 shows a sketch of a plume diffusing in an estuary. The vertical and horizontal extents of the plume and the time required for approximately complete mixing can be predicted at least within an order of magnitude in most cases, but if more exact results are needed prototype dye dilution studies are usually required.

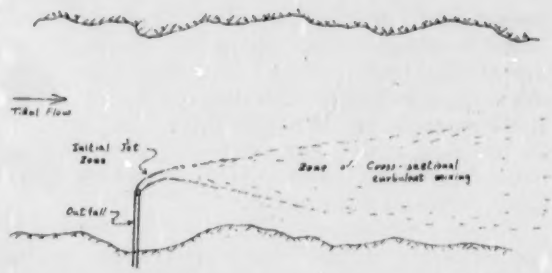

FIGURE 6.—A sketch of the zones of mixing from an outfall in an estuary. The direction of the drift changes with the changing tide, but during the tidal flow the pattern is as shown. At slack tide there is a build-up of concentration near the outfall.

STATUS OF PREDICTIVE CAPABILITY

Analytical Models

The use of analytical models is generally limited to estuaries which are long and narrow and can be considered to be one-dimensional. A basic assumption of most analytical models is complete mixing across the cross section, as in the empirical analysis described in the previous section. The use of analytical models is limited partly by their one-dimensionality, and partly by the need to assume some value of a longitudinal dispersion coefficient, whose magnitude is difficult to predict. Analytical models are sometimes useful; for instance, O'Connor (1965) gives analytical solutions for distribution of dissolved oxygen and biochemical oxygen demand in several estuaries. Recently, attempts have been made to relate the longitudinal dispersion coefficient to the salinity gradient in order to predict salinity intrusion analytically (Thatcher and Harleman, 1972, and Fisher, Ditmars, and Ippen, 1972). These efforts remain in the research stage, however, and in general it can be said that analytical models are not a dependable predictive tool unless based on empirical observations of salinity distribution.

Numerical Models

The past 10 years have seen considerable effort and progress in the development of numerical models for marine pollution. Numerical models usually consist of two parts; first, a model of the tidal hydrodynamics, and secondly, a model of the transport and reaction of pollutants carried by the tides. At the present time virtually all operative numerical models are two-dimensional. That is, the velocities and transports are considered to be only in horizontal directions along and across the estuary. The hydrodynamic portion of the model predicts the vertically averaged velocity vector at various grid points within the estuary, and then the transport portion of the model simulates the motion of pollutants which are carried by the computed velocities. Some numerical models use a fixed rectangular grid, while others use link and node arrangements or variable grid spacings so that the grid spacing can be adjusted to fit the requirements of different parts of the estuary.

Numerical models are in current use to study pollution problems in a number of estuaries. The state of the art can be shown by three recent examples. Figure 7 is from a report of a study of pollution in Boston Harbor by the firm of Hydroscience, Inc., completed in July 1973. The study used the hydrodynamic model developed by Leendertse (1967) to

predict tidal velocities throughout the harbor. Pollutant distributions were computed for a number of hypothetical releases of unit waste loads; the figure shows the distribution 12 hours after a unit release at the mouth of the Neponset River. The results of the modeling study were used to predict concentrations of pollutants resulting from alternative water quality management schemes.

The second example is from a study of the dispersion capability of San Francisco Bay-Delta waters by the California Department of Water Resources. Figure 8 shows the computed distribution of pollutant discharge. The methodology of this study was somewhat different from that of Boston Harbor because of the much greater size of the bay. The north bay was modeled by a series of one-dimensional segments, and the south bay by a two-dimensional arrangement of segments. The scheme was probably not as accurate as the Boston Harbor scheme, but the scheme used for Boston Harbor requires much more computer storage and running time and to date has not been used in an estuary approaching the size of San Francisco Bay.

The third example is from a study of the dispersion of wastes from a proposed industrial outfall in the Delaware River. Figure 9 taken from a paper by Fischer (1974), shows predicted and observed distributions of dye in the river 10 days after the beginning of a continuous release. In this case most of the spreading was due to transverse mixing and the shear effect; the numerical model used, as described in the report, was specifically designed to model these effects.

Since numerical models are being used so widely, it is important to recognize that they will have limitations. The models seem to do a good job of computing the effects of tidal pumping and chopping. Wind-driven circulations can be predicted, although our knowledge of the wind stress coefficient is limited. Most numerical models do not model the shear effect very well, partly because the true magnitude of the transverse mixing coefficient is not well known, and partly because the numerical processes tend to obscure the rate of diffusion in the model. The greatest limitation of numerical models, however, is their inability to account for stratification or gravitational circulation. At the present time, numerical models of the effects of stratification are strongly empirical. In some cases two-dimensional models which consider only a vertical plane have been used, with some success, but in many estuaries, gravitational circulation and stratification have important three-dimensional components and no model is adequate. Finally, it should be stressed that the transport portion of most

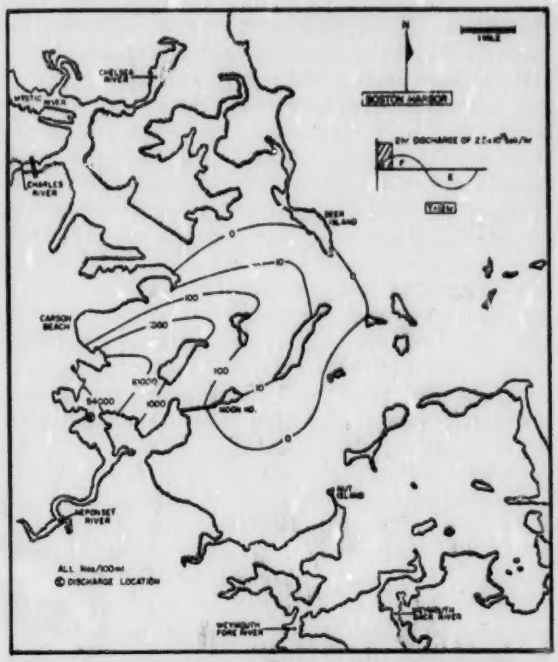

FIGURE 7.—A predicted distribution of pollutant concentration in Boston Harbor resulting from a two-hour discharge at the mouth of the Neponset River. This figure is from a report of a study by Hydroscience, Inc., to the Massachusetts Water Resources Commission.

numerical models has received very little field verification. For instance, the distribution shown in Figure 7 has not been verified in the bay itself. Even the hydrodynamic models lack extensive field verification, and their results must be viewed with caution.

Hydraulic Models

Hydraulic models have been in use for many years to study such problems as sediment transport, velocity distributions, and the effects of projects such as construction of barriers and harbors. Recently, hydraulic models have also been used for pollution studies. For instance, the San Francisco Bay-Delta model is being used to study the effects of the peripheral canal and a proposed ship canal on intrusion of salinity into the Delta. Hydraulic models have also been used to study the distribution of an effluent from an outfall, by arranging an injection of a tracer into the physical model. Where a model has already been built for other purposes, use for a pollution study is relatively inexpensive.

Hydraulic models, like numerical models, are capable of representing the effects of tidal pumping

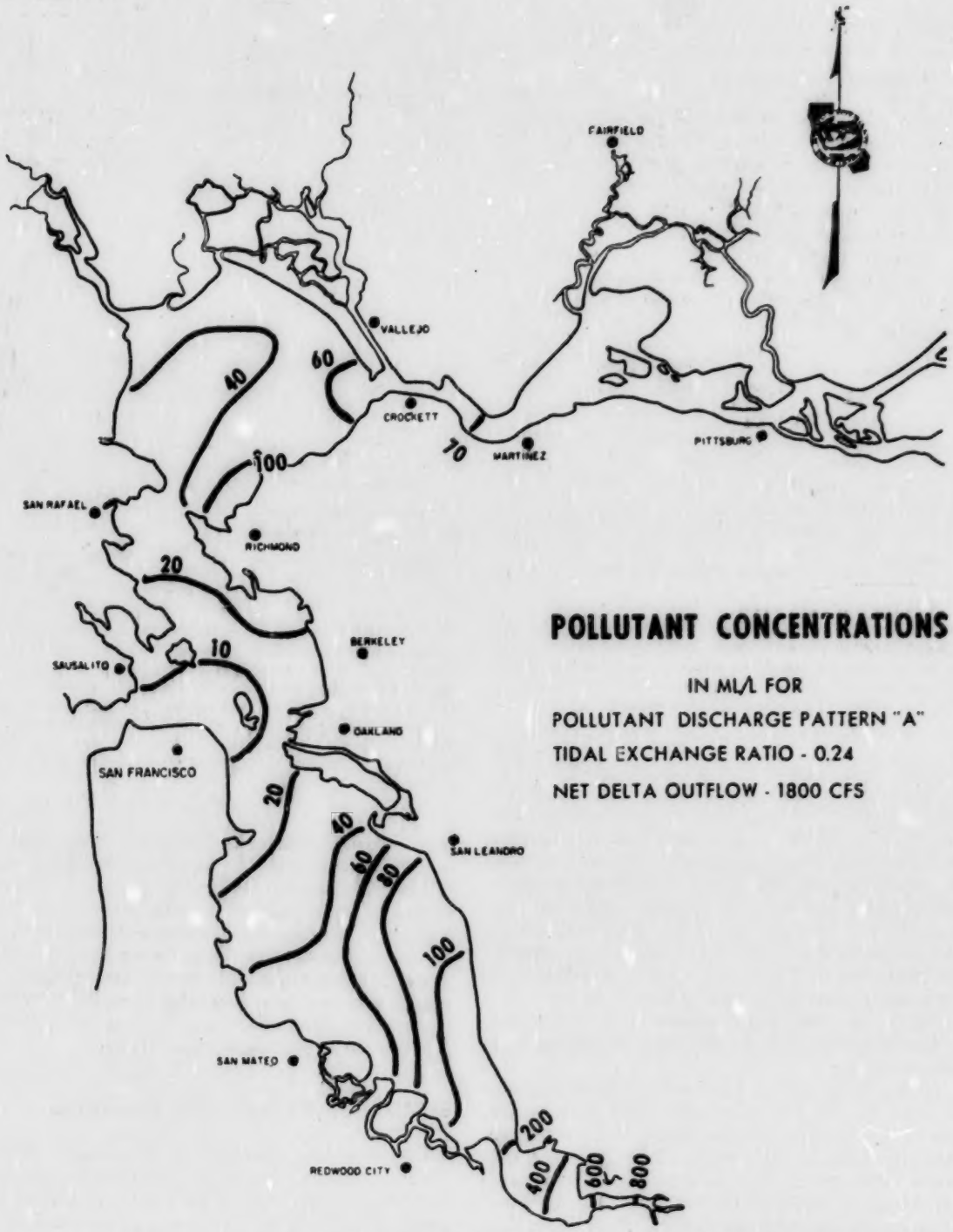

FIGURE 8.—A predicted distribution of pollutant concentration in San Francisco Bay resulting from a stipulated set of inputs, taken from a report by Nelson and Lerseth to the California Water Resources Control Board.

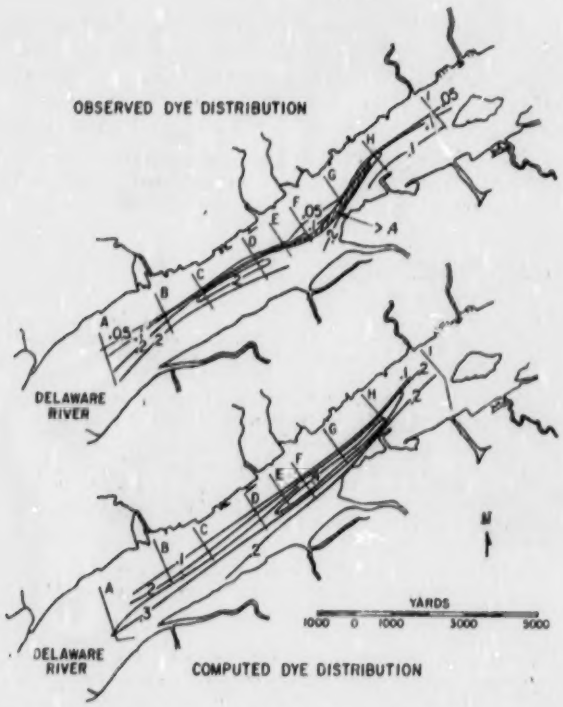

FIGURE 9.—Computed and observed distributions of dye released from the site of a proposed industrial outfall in the Delaware estuary. The dye simulates the spreading of the proposed waste discharge, and the dye results can be used to compute expected concentrations of pollutants.

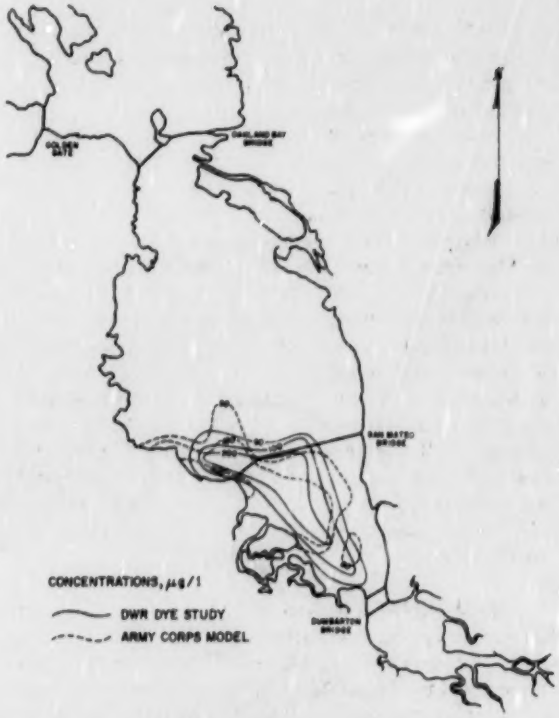

FIGURE 10.—A comparison of the spread of dye in a physical model of San Francisco Bay and in the bay itself. The dye was released north of the San Mateo Bridge near the west shore. The dashed lines are concentrations observed in the U.S. Army Corps of Engineers model; the solid lines are concentrations observed by the State of California Division of Water Resources in the bay (corrected for dye loss). Both distributions are five tidal cycles after beginning of release of the dye.

and chopping, because they are adjusted to produce the proper currents. Hydraulic models also represent the effects of stratification, although perhaps not exactly. Where three-dimensional circulations and stratification are important a hydraulic model is probably as accurate a tool as any for predicting effects of circulation, even though there is dispute over the accuracy of the results. Figure 10 shows one comparison of dispersion of dye in an estuary vs. dispersion of a similar release in a model. Unfortunately, not many such comparisons exist because of the very large amount of dye required in the prototype and the difficulty of making field measurements.

Hydraulic models do have one serious limitation. In order to conserve space and maintain turbulent flow it is necessary that the model be distorted, so that the depth is relatively much greater than the width. This means that near source distributions are distorted, and that the turbulent mixing processes are not properly represented. Thus, hydraulic models sometimes will not properly represent the near field or medium field concentrations from an outfall, even though the far-field distribution may be reasonably correct. Hydraulic models are perhaps best used in a qualitative sense; various different arrangements of outfall locations or various different designs for construction projects can be tried in the model, and the results compared. Even though the results may not be quantitatively exact, comparative results will usually determine which design will produce the least degree of pollution.

SUMMARY AND RECOMMENDATIONS

Estuaries can assimilate more waste with less effect on the environment than can the rivers which feed them, because of the flushing current from the ocean. There is a simple procedure for estimating the flushing current, based on measurement of salin-

ity in the estuary. In many cases this procedure can be used with reasonable accuracy to predict the concentrations of wastes resulting from an industrial or municipal discharge.

In several types of cases this simple procedure does not work: in estuaries of nearly constant salinity or very wide estuaries and bays; in fjords or strongly stratified estuaries; or where the shape of the estuary is to be changed by major construction. In these cases some form of hydraulic or numerical modeling is needed to predict the effects of waste discharges. Modeling, however, requires an understanding of the type of circulation to be expected in the estuary and an understanding of the limitations of the types of models available. Modeling is not an art for the semi-skilled; there is no one model suitable for use in all estuaries, and at present a relatively small number of individuals have the training and experience required to do useful modeling studies.

These considerations lead to the following recommendations:

1. It should be understood that modeling is an art for extremely qualified experts and that sophisticated numerical models are not a necessary part of every water quality plan. Models should be used only where they are really needed, and then only by persons with extensive familiarity with the model and its limitations. Use of the wrong model can be worse than use of no model at all.

2. There should be a national listing and classification of estuaries to determine in which portions of which estuaries the simple procedure for estimating flushing currents is suitable, and in which it is not. Such a listing would be of great use to EPA in setting standards and proposing rules, as the Agency could then specify the use of the simple method where allowed by the listing, and require other methods where the simple method is not allowed.

3. Continued research, development, and training in the use of models is essential. This research should include more complete verification of the accuracy of present models, further development of numerical models, and further investigations of the limitations of numerical and hydraulic models. As part of the research there should be a vigorous program of specific field testing of present and proposed models. This research will have the benefits of producing more generally applicable and dependable models plus the desirable byproduct of increasing the pool of persons qualified to use the models.

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THE CRUCIAL ROLE OF SYSTEMATICS IN ASSESSING POLLUTION EFFECTS ON THE BIOLOGICAL UTILIZATION OF ESTUARIES

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ABSTRACT

The data of systematics form the essential foundation for pollutional biology. Living targets of pollution must be identified precisely; imprecision nullifies results and renders them nonreplicable. Most estuarine and coastal marine plant and animal groups are poorly known systematically. Major bottlenecks in the application of systematics to the problems of environmental pollution result from the critical shortage of experienced systematic specialists and technicians, as well as lack of inventories of specialists, identification publications, and identification services. Although water quality legislation implies the need for identification of organisms involved in analyses of the biological impacts of pollutants, there has been no conspicuous financial support for systematic work. Because basic and applied environmental research and its application to the practical problems of pollution have grown far more rapidly than the supporting base of systematic biology, it is imperative that existing human and material systematic resources be conserved, and their further development be encouraged. Specific recommendations are offered to maximize the service role of biological systematics in the identification and assessment of the effects of pollution on the biological utilization of estuaries and coastal waters in the United States.

INTRODUCTION

In the course of perhaps four billion years the surface of the earth has become populated by an estimated 10 million kinds of recent organisms, ordered in self-sustaining, self-regulating, ecological systems. About one million species of animals and a half million species of plants have been described, and an estimated additional half billion species are extinct in fossil strata (Mayr, 1969). Evolution tends to sustain these living systems, accumulating complex arrays of organisms that stabilize the environment, and conserve and reuse resources to support the maximum amount of life; whereas disturbance causes a systematic alteration of biotic structure (Woodwell, 1969, 1974). Estuaries, biologically complex, delicately balanced, coastal transitional zones where seawater is measurably diluted by land drainage are integral parts of the biosphere. If not perturbed, they likewise tend to be stable, self-sustaining, self-regulating, biologically productive systems (Carriker, 1967).

But human tenants on the shores of estuarine ecotones, through heedless technological activities and massive discharge of deleterious residues, continue severely to disturb these coastal zones (Ketchum, 1972). The consequences are eradication of habitats; reduction, alteration, and extinction of species; and impairment or destruction of the qualities fundamental to the health of the biosphere and the welfare of humans. The critical role of a wide diversity of organisms in promoting the health of the estuary is indisputably clear. We reaffirm with Woodwell (1974) that humanity lives as one species within a biosphere whose essential qualities are determined by other species and that we must give careful thought to these relationships. There is urgent need, accordingly, to examine in some depth the functions of systematics in the identification and assessment of the effects of pollution on the biological utilization of estuaries. This will be done in this paper.

What is Systematics?

Systematics may be defined as the scientific study of the kinds and diversity of organisms and of the relationships among them (Simpson, 1961). Although the term taxonomy is often used for the theory and practice of identifying and classifying organisms, systematics and taxonomy are often loosely treated as synonymous (Davis and Heywood, 1965); this will be the practice in this paper.

Systematic biology provides scientific names for organisms, describes them, preserves collections of

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them, provides classifications for them, keys for their identification, and data on their distributions; it investigates their evolutionary histories, and considers their environmental adaptations (Michener, 1970). Systematists now study organisms in all stages of their life cycles, disclosing unexpected structural details by the use of scanning electron microscopy, analyzing behavioral patterns and chromosomal configurations, and comparing the sequences of amino acids in protein and nucleic acid molecules.

Systematic biology is perhaps the oldest of the sciences, and is closely allied and complementary to ecology. Systematics is one of the fundamental perspectives in biology, integrating such disciplines as ecology and behavior with functional morphology, comparative physiology, biochemistry, genetics, and evolution.

Why Identification?

The data of systematics form the essential foundation of all other biological disciplines, especially of such interactive sciences as marine biology, biological oceanography, estuarine ecology, and pollutional biology. Wilson (1971) rightly points out that most of the central problems of ecology can be solved only by reference to details of organic diversity, and that even the most cursory ecosystemic analyses have to be based on a sound systematic treatment of the organisms considered. Pollutional ecology is no exception.

The basic functional unit in biology is the organism. Similar organisms are grouped by systematists in a species and given a scientific name, a symbol for the recognition of the taxon. Historically, precise and complete identification of organisms has not been available for many species, and has commonly been inaccurate for others. It is crucially important that the biologist know the precise identity of the organisms he studies—even more so now in view of the growing universal emphasis on estuarine and coastal marine environmental work.

The identity of microbes, plants, and animals is as significant to the microbiologist, botanist, and zoologist, respectively, as proper identification of elements, molecules, and compounds is to the chemist. Or stated in another way, the systematics of the whole organism is no less significant than that of the molecules of which it is made (Hedgpeth, 1961). Higgins (1974) notes that we have to learn to identify the living targets of pollution with the same analytical competence as the chemist identifies the elements, and to identify community structure in the same way the analytical chemist deals with his compounds. The increasing refinement and quantification of biological investigation requires comparable exactness in the identification of organisms used in both basic and applied research. Imprecision in identification neutralizes research rigor! If identifications are in error, published work becomes nonreplicable, and thus unscientific. In view of this significance, we examine next the utilitarian aspects of systematics in estuarine and coastal marine work.

Biological Censuses and Environmental Assessment

Because differences in species reflect differences in structure, function, and requirement of organisms, the first step in any biological study should be identification of the organisms under investigation (Allen, 1974; Carriker, 1967; Steere, 1971). Hedgpeth (1957) cogently summarized the argument with reference to ecology: "... an ecological investigation is essentially a study of organisms *in situ* ... The primary data of any ecological investigation, therefore, are the species of organisms concerned ... The first procedure in an ecological investigation is, or should be, essentially an exercise in systematics, the identification of species, and understanding, *inter alia*, the relation of these species to other groups in both the evolutionary and physiological senses." The significance of specific names to ecologists may be illustrated by this excerpt from a letter received by Schmitt (1953): "I have all of my voluminous field notes ready and only await the names of the specimens which I sent you a long time ago. Have you had a chance to go over them? I have the names of most, but there are still many left and I can publish nothing until I get them." Elton (1927) concludes that one of the biggest tasks confronting anyone engaged in ecological surveys, owing to the lag of the systematic study of some of them, is that of getting all groups identified to the species. A popular method of studying phytoplankton in the sea, which has purportedly obviated the need for specific identifications, employs continuous plankton recorders and chlorophyll extraction. Recent research in mariculture, however, has demonstrated the nutritional role of some species of phytoplankton, and the nuisance value of others (Epifanio and Mootz, 1974), evidence that number of individuals and identification of chlorophyll are insufficient to identify the value of species.

The magnitude of the task of conducting sound biological censuses in order to obtain a reasonable picture of biological conditions even in a limited geographic area is difficult to comprehend in terms of people, time, and money. Nonetheless, in this

decade "before and after" surveys have become routine operations at sites of power plants and other technological enterprises. Various commercial groups have sprung up about the country to conduct the work. Unfortunately, some of this work tends to be superficial and lacks taxonomic credibility. To illustrate the magnitude of the job of conducting thorough, systematically sound, biological censuses, I will summarize three. These range in emphasis from basic to applied.

Open ocean.—The first was a fundamental study of the biota on a course some 5,880 miles long west of Mexico, Ecuador, and Costa Rica, and in the Caribbean (Schmitt, 1939, 1953). In 24 days at sea, Schmitt and associates collected some 11,000 biological specimens at 14 stations. Preliminary sorting was done as birds and fishes were frozen and invertebrates and plants were chemically preserved. Further sorting by two experienced biologists at the Smithsonian Institution, so that the material could be distributed to specialists for identification and classification, required about two weeks. Shipping to out-of-town taxonomists, and their acceptance and reporting extended over 35 months. Specimens went to nine different divisions in the Smithsonian and to 21 specialists in four foreign countries and the United States. Three years after distribution of specimens began, most of the reports from specialists were in hand, and by the end of another year most of the reports were in print. In summary, 26 active taxonomists were involved over a 3-year period; the 19 systematic papers published as of 1953 covered a collection of 191 families, 330 genera, and 469 species of animals, and 41 families, 70 genera, and 87 species of plants!

Cape Cod Bay.—The second is a quantitative biotic census undertaken in 1964 in Cape Cod Bay, Mass., by the Systematics-Ecology Program, Marine Biological Laboratory (Young et al., 1971). The aim of the census was to provide a synthesis of information on the kinds, abundance, distribution, and diversity of benthic estuarine invertebrates retained on a 1 mm mesh screen, in relation to particle size and organic content of the sediments, depth, temperature, and salinity in an as yet relatively undisturbed embayment. The bay was divided into 300 one-mile square grids, and alternate quadrats, about 100 of them, were sampled with four different types of gear. Samples were washed and preserved on board the research vessel, and hand sorted and identified at least to the family level in the laboratory prior to being distributed to systematic specialists. A total of 47 taxonomists collaborated in the identifications. The field work consumed some five years, and six more years were required for final sorting, distribution of specimens to specialists, return of the reports, computer analyses, and preparation of final reports. The local work at the laboratory involved eight different senior people and approximately 40 to 50 full and part-time sorters at different times over the 11-year period of the project. In all, a total of 237 families, 485 genera, and 782 species has been identified (Michael, 1975; O'Connor, 1975).

Connecticut River.—The third census is a pre- and post-operative long-term study at the site of the Connecticut Yankee Atomic Power Company nuclear generating station at Haddam Neck in the tidal region of the Connecticut River. The survey was designed to examine possible changes in the physical, chemical, and biological features along a 5-mile stretch of the river in the vicinity of the plant after appearance of the warm water plume. The study was begun in 1965 and will be completed this year (1975), 10 years later. When the plant began commercial operation in 1968, it was one of the largest nuclear plants in the world. A staff of 10 to 12, based at the Essex Marine Laboratory, on the Connecticut River, conducted the study (Merriman, 1973, 1974). In the course of the study, some 20 systematists assisted with identifications. A total of approximately 6,500 biological samples were collected, including about 150 species of bacteria, plants, invertebrates, and finfish. The final report, to be published as a single volume, will contain approximately 200 printed pages.

The question may arise as to whether such long-term, time-consuming, expensive censuses are necessary. Regrettably, obvious substitutes to this approach are not currently available; no better barometers of the biological impact of perturbations exist than organisms themselves, and there is yet no other way to obtain baseline information prior to the impact of perturbations. Identified organisms and general information about them (that is, systematics collections) still constitute the fundamental resource for basic evidence and assessment of what has occurred, what is occurring, and what can be expected to occur in the environment (Allen, 1974).

STORAGE AND RETRIEVAL

Accurate identification is the key which unlocks the storage and retrieval system of scientific information. All knowledge published on organisms is cata-

logued and stored in the world scientific literature under the scientific name of the species, or where the systematics is incompletely known, under the names of higher taxa in the classification. If nothing has been reported on a newly described and named species, its identification permits accumulation of information for future use. Accurate retrieval of information, consequently, can only be as reliable as precision of identification and classification. Names make information accessible on such aspects of organismic biology as geographic distribution, ecological relationships, life cycles, behavior, comparative physiology, host-parasite relationships, predators, disease organisms, biological and chemical controls, and response and tolerance to adverse environmental changes.

PREDICTIVE ATTRIBUTES

Michener (1970) indicates that placement of a species which has been inadequately studied in a genus and family makes possible prediction of some of its biological attributes. Although this may be a helpful practice under some circumstances, there are so many exceptions that it is not recommended for the non-specialist. There is serious danger that unfamiliar with species, he may apply the rule of thumb and draw false conclusions (Burbanck, 1975). Allen (1974) notes that in current extensive testing programs for determining tolerance levels of species exposed to pollutants, species that are similar in appearance do not always respond similarly physiologically. Such considerations underscore the importance of precise identification at all levels of biological work.

ELIMINATION OF DUPLICATION

Needless duplication of biological research—which is becoming increasingly costly and time consuming—can be avoided by a careful check of the world scientific literature. It is not uncommon for research to be repeated unnecessarily because the investigator did not consult the literature with sufficient thoroughness, or because identification of his organism(s) was in error. Libraries, unfortunately, store too many examples of the results of very expensive research which have been discredited because of faulty identification of species (Allen, 1974; Clausen, 1942; Sabrosky, 1955). Stunkard (in Schmitt, 1953) succinctly summarized the problem: "Much of the fumbling and stumbling in biological work can be traced directly to the failure of the investigator to recognize the organisms with which he worked." As a safeguard against repetition of error, it has become increasingly necessary that an identified sampling of species (voucher specimens) mentioned in publications be deposited in permanent accessible museums or herbaria so that scientists can check the accuracy of identifications in the literature, and consequently the reliability of the publication (Allen, 1974).

YARDSTICKS

Through accurate scientific names and preserved biological specimens, species collected at different times can serve as a yardstick for determining changes which may have, or will, take place. Thus, over a long period of time, systematics collections can play a part in revealing the rate at which evolutionary changes occur. For baseline information IDOE (1972) recommends storage of uncontaminated representative samples of plankton, fish, marine plants, and so on, in a museum specially designed for preservation of environmental voucher specimens (organisms, water, sediment, and air particles) where subsequently they may be used as indicators of normal levels of pollutants.

Some species of living organisms, more sensitive to environmental deteriorational stress than others, provide warning signals of pollution by physiological or behavioral responses; while other species, less affected by environmental change, respond to the changes by unusual increases in abundance (Olson and Burgess, 1967). Shuster (1974) suggests that by identifying the species most sensitive to pollution, workers might recognize the impacts of pollution long before it affects common, generally less sensitive, species. Thus recognition of a "sick" ecosystem might not require a species-by-species accounting. The stickler here is the problem of recognition of species sensitive to specific pollutants, to what degree such species could serve as accurate barometers for the health of an entire ecosystem, and whether they have been insensitized to the pollutant through prior exposure. Rare species, possibly because they may live closer to the limits of critical environmental factors than common species, may make more sensitive indicators than common species. Burbanck (1975) suggests that we place more emphasis on noncommercial organisms as indicators. Since they have no economic value and are thus less disturbed by human collecting devices, they might constitute more sensitive indicators than species periodically buffeted by collectors. He also believes that true estuarine species might be more sensitive than marine species which move in and out of estuaries.

BIOLOGICAL CONTROLS

Accurate identification will also become critical as the use of pesticides is replaced by specific control organisms. These species are often difficult to distinguish from closely related and nearly identical forms that feed on different hosts. To date little has been done to control estuarine and coastal marine pests by other organisms.

INDUSTRY, FISHERIES, AND CONSERVATION

The following striking examples were cited by Schmitt (1953, 1954) of the value, often with substantial monetary return, of identification in these fields.

1) Marine bivalves penetrated the outer casing of a power cable lying on the bottom of the bay between Palm Beach and West Palm Beach, Fla., in the 1940's, causing a series of serious blowouts. Adult burrowing bivalves were identified as a new species incapable of escaping from their burrows. The problem was easily solved by burying the cable beneath the bottom of the bay where the molluscs suffocated.

2) A specialist on the systematics of benthic sipunculid worms was asked in 1953 for copies of his technical publications by an Alaskan cod fisherman who had found that where these worms occur he made good hauls of fish. The fisherman wanted to plot the distribution of the worms in order to enhance his fishery and extend his operation.

3) In 1954 a sport fisherman took a specimen of a mantis shrimp to a national museum. He sought information on its mode of life, distribution, and abundance. A systematist, after identifying the specimen, learned from the literature that the stomatopod is the favorite food of certain panfish taken by fishermen in the Chesapeake Bay—and thus the sport fisherman's interest in the species.

4) In the Carolinas shad enjoy legal protection. In order to catch violators and enforce the conservation laws, state conservation agents must be able to distinguish between four or five species of fish, all superficially more or less alike.

HOW DOES SYSTEMATICS AID IN IDENTIFICATION AND CONTROL OF POLLUTION?

Pollutional biology is a subdivision of ecology, and serious ecologists recognize that their work must be based on sound specific identification of the organisms they are interpreting (Humes, 1974). Patrick (1949) was one of the first to stress this in the evaluation of the kind and duration of stream pollution. Her research demonstrated that there is no satisfactory shortcut which avoids identification of species involved. Tarzwell (1974) in the course of some 40 years of investigating pollutional zones of streams in various parts of the country, discovered that what may be considered sensitive or resistant species in one stream may not necessarily be so in another stream; in a different region these sensitive or resistant species may be replaced by closely related species. He also found that characterization of population changes in streams over time as waste is introduced can be made only by specific identification of organisms. Pawson (1974), furthermore, stressed that to understand interactions between organisms and pollutants, one must be quite sure that the organism in question represents one species, and not a group of several species.

Systematic studies are also essential in establishing the quantitative characteristics of estuarine communities before real or possible pollution occurs; otherwise, effects of pollution may not be detectable (M. Abbott, 1974). Tarzwell (1974) noted that it is both the qualitative and quantitative composition of the biota of streams which indicate the severity of pollution and the distribution of pollutional zones. To control pollution, therefore, we must know the organisms affected and be able to recognize introduction and extinction of species (Turner, 1974). The need and value of accurate identification in pollutional biology are also emphasized by Pimentel (1971) in a publication for the Office of Science and Technology on the ecological effects of pesticides on nontarget species, and by Battelle (1971) in a report for the United States Environmental Protection Agency on the effects of chemicals on aquatic life. Unfortunately, misclassification of *Balanus* sp. under the phylum Mollusca in the latter work tarnished the credibility of the systematic emphasis.

Some workers recommend the use of diversity indexes for detection of the effects of pollution on the community as a whole. A species diversity index, however, being only a single parameter of a complex system, has merit only if cautiously interpreted (Hedgpeth, 1973), and provided, as should be the practice, that species are carefully identified. This is not always the case. Some investigators identify and count microorganisms only to suborder and family, and employ these taxa for calculation of the indexes (Allen, 1974). We must emphasize that proper systematic skills and familiarity with species-differentiating traits are necessary to construct accurate indexes (Williams, 1974). In spite of the general

value of indexes, however, individual species cannot be overlooked: changes in their abundance may occur which are not detectable by the index alone (Watling, 1974). To be properly used, species diversity should also include the complexities of life cycles and trophic levels (Burbanck, 1975).

There is a tendency among some workers, when dealing with groups of organisms which are difficult or not well known taxonomically, to carry identifications only to familial or genetic levels. Turner (1974) argues with reason that this is simply not enough! By taking her identifications to the specific taxon, she was able recently to recognize introducton of tropical species of the wood boring bivalves, Teredinidae, into the warm water discharge canal of a nuclear generating station in New Jersey. Had she identified the borers only to genus, she would have missed the tropical introductions altogether, and this critical aspect of the impact of the power plant on its local estuarine environment would have gone unnoticed.

Systematics can be used to considerable advantage in assessing the effects of changing environmental conditions by recognition and study of variations in the morphology of organisms. The method has been little explored and merits much more attention. Estuarine species may be more plastic than oceanic forms, and may thus reflect the effects of pollution more readily (Watling, 1974); Rasmussen's (1973) documentation of the variability of the genus *Gammarus* in his study of the Iscfjord fauna is a good example of morphological plasticity. Remane and Schlieper (1971) recorded other examples.

Success in reducing or eliminating low levels of harmful pollutants, recognized only with difficulty by chemical means, is determinable biologically and with reliability by the responses of the organisms affected. Some pollutants may exert their effects in very minute amounts over long periods of time. Exposure to sublethal concentrations of detergent, copper, and zinc, for example, caused fatal anatomical abnormalities in the second generation of the polychaete *Capitella capitata* (Reish et al., 1974). Other pollutants may be progressively concentrated in food chains, and still others may interact synergistically. The latter may result in insidious alteration of aquatic environments, especially of estuaries (Odum, 1970). Yet additional organisms, preadapted to survive or thrive in certain polluted environments that are noxious to most other organisms, become indicators of that pollution (Olson and Burgess, 1967). Systematic knowledge of "normal" biotic structures provides the base for comparison with that of poisoned communities.

One of the potentially most damaging categories of change which can be brought about by man, resulting in decimation of entire species, is loss of genetic information through pollution-induced environmental change. Processes leading to extinction of large animals and plants are no longer likely to go unnoticed even if they cannot be interrupted. In certain cases predictions of immediate consequences, such as Cousteau's recognition of potential change in the oceans should filter feeding whales be eliminated, are recognized. However, dearth of information on small estuarine metazoan organisms, like nematodes, prevents any reasonable capacity for predicting the consequences of pollution to the environment in the context of these small invertebrates. Although levels of pollution are probably most effectively measured by physical and chemical techniques, impact of pollution is best measured in life systems, and thus the requirement to recognize the total dependence of pollutional ecology—no, all ecology—upon the sophistication and thoroughness of its foundation in systematics! The consequences of pollution to the earth and to man are of such magnitude that a compelling case is readily made for the study of a broad spectrum of micro-, meta-, and macroorganisms in assessing any influence of pollutants. However, such undertakings remain so primitive and inadequately supported that a major research effort, to be measured in decades, is still required to determine the full extent to which systematic knowledge, especially of small organisms, can significantly aid in the identification and control of pollution (Murphy, 1974).

What is said by Murphy about small metazoans in the identification and control of pollution, applies to an even more critical degree to such ubiquitous, abundant, estuarine microorganisms as fungi, yeasts, bacteria, viruses, and so forth. Bacteria, for example, are more important than most of us realize in pollutant transfer, biological degradation, carbon assimilation, and possibly in the control of soluble concentrations of elements (Alexander, 1973). Viruses, minute, highly mutable agents, are common in estuaries, move in the ground water, and inhabit water reuse systems, but lack of information on their behavior in these systems has impeded development of the reuse of water. Cooke (1969) is pessimistic about the emergence of general descriptions of the remarkably complex behavior of natural populations of microorganisms in native waters, and notes that research on the role of microorganisms in pollutional biology must include study of specific chemical compounds and measurement of their degradation products. I would recommend, in addition, that the research must include intensive systematic investigations (a) to provide the essential scaffolding

upon which to hang the results of the pollutional research and (b) to aid in its interpretation.

Summary.—Field systematics aids in the identification of the kinds, distribution, severity, and duration of pollution at individual, populational, community, and ecosystemic levels. It does so by revealing (a) changes in the proportion of abundance of individuals, (b) alteration in the composition of species (by elimination of some and introduction of others and changes in ecological succession), (c) modifications in morphology, physiology, ecology, behavior, and development at individual and populational levels, and (d) emergence of hardy indicator species which survive or even thrive in the altered environment. Systematics also aids in identifying laboratory experimental organisms for study of the biological effects of pollutants on them, and their responses to the pollutants.

Systematics contributes to control of pollution in the sense that populations and physio-ecological systems, which themselves function in reducing or rendering innocuous the effects of pollutants, can be recognized and augmented. Such species systems are abundant, especially in the microbiological realm where they serve as shock absorbers in buffering the effects of chemical perturbations.

Beneficial Effects of Increase in Systematic Knowledge and Services

An increase in knowledge and services in systematics will accelerate the rate, and make possible expansion, of systematics-dependent environmental investigations currently in progress. It will also open to investigation problems not now undertaken because of the difficulty or impossibility of obtaining needed identifications. Questions are not now being asked on the identification and control of pollution, or go unanswered or are delayed, because of inadequacy of identification services and facilities; answers to these questions would probably materially enhance biological assessment of the impacts of pollution, and thus of pollution control (Michener, 1970). The interstitial fauna, for example, are poorly known (Hulings and Gray, 1971), yet intertidal beaches and tidal marshes in estuaries are the first zones to be attacked by floating pollutants. Comprehensive knowledge of these fauna might reveal improved ways of determining the impact of the various fractions of these pollutants. Adequate knowledge of interstitial organisms, most of which are minute and many are abundant, would make available large numbers of them for the assessments.

A decrease in knowledge and services of systematics would unquestionably mean that causes and effects of pollution would remain unknown or confused (Wigley, 1974). Pollutional researchers would find themselves in the same situation faced by many physiologists who a few years ago based researches and conclusions on improperly identified organisms (Humes, 1974). Under these circumstances possibilities for duplication of experimental work or for making comparisons of seemingly similar situations would be slender indeed, and in fact, any comparisons would be automatically invalid (Pawson, 1974). If one remains unsure of the organisms he is dealing with, results of investigations based on them will likewise be questionable and uninterpretable. In this regard, closely related species, particularly sympatric species, must be very carefully identified.

Should systematics not be supported, Turner (1974) envisions a decreasing number of systematists, and chaos when scientists report experimental results on incorrectly identified organisms. Higgins (1974) stresses that no cause and effect analyses of any ecosystem can occur without precise identification of both the biotic and abiotic components, and because of its extraordinary complexity, this applies to the estuarine ecosystem above all others. Murphy's (1974) concern, if systematics continues at its present low level of support, is that international, national, and local policy directed at pollutional control, and purportedly based on ecological considerations, will continue to be pursued with a totally inadequate data base.

WHAT HUMAN ESTUARINE ACTIVITIES REQUIRE IDENTIFICATION SERVICES?

Allowing the world ecosystem to function in a viable, healthy way is a responsibility as well as an awesome challenge to man. The responsibility can be met, in part, by maintaining a high level of biological diversity which is commensurate with biotic stability and insures against the onslaughts of climate and disease (Steere, 1971). But a pervading thrust, intrinsic in man's recreational, fishing, technological, and control activities is making the task of preserving diversity increasingly difficult. Nowhere on the globe is this thrust more stridently evident than along coasts and estuaries. Organisms, including much of the human population, find themselves unwillingly embroiled, often helpless victims, of biotic instability in increasingly ravaged environments.

Since kinds of species and numbers of individuals are ingredients of diversity, it is necessary that periodic biotic assessment of the impact of man's

Table 1.—Human estuarine activities requiring identification and classification of organisms

Activity	Organisms
Recreation	Species harmful or potentially harmful in recreational activity which takes people into the water, or in the course of which there is danger of falling into the water; example, sea nettles.
Sports and commercial fishing	Species taken commonly such as finfish, as well as species which could be taken but because of custom are not, such as squid and conchs; potentially poisonous species, as shellfish causing paralytic poisoning in man.
Artificial structures	Species influenced by, affecting, or associated with manmade bulkheading, piling, wharfs, anchors, buoys, island structures, barnacles.
Construction and operation of power plants	Species associated with, influenced by, or affecting cooling waters, thermal plumes, cooling towers, radioactive discharge, and plant conduits through which water passes; attached algae.
Exploration and development for oil and gas	Species associated with, influenced by, or affecting exploration, rigs, towers, pipe lines, etc.; spills and discharges; fouling organisms of all kinds.
Extraction of minerals	Species influenced by, affecting or neutrally associated with mining of sand, gravel, metals, and other mineral resources (less gas and oil); surf clams.
Sediments: dredging and filling	Species influenced by, affecting, or associated with sedimentation and erosion resulting from this activity; tube worms, oysters.
Placement of wastes	Species influenced by, affecting, or associated with the dumping of liquids and solids, or involved in effluent sinks; mussels.
Biological control	Species used in control as well as those affected directly or indirectly by biological control; none yet employed in coastal waters, but approach is promising.
Chemical control	All target and associated non-target species in the area of pesticide spraying, intertidal oysters and mussels.
Ecological surveys (pollutional)	Basic surveys; wherever possible all species sampled; applied surveys: as representative identification as possible (the problem: don't always know what species are representative of communities).
Impact statements	All species known, or postulated to be involved, in anticipated activity.

activities be made. A brief catalogue, suggestive of those activities in which estuarine organisms require systematic identification, is presented in Table 1.

What Organisms Should Be Identified?

Only a few non-taxonomists appreciate how poorly most plant and animal groups are known taxonomically. A striking illustration of this was presented by Remane's work on the microscopic marine fauna of the Kieler Bucht, an area previously considered to be well known. By thorough search and with the application of new methods, Remane found 300 new species, including representatives of 15 new families, in 10 years (Mayr, 1969)!

In time, with improved systematic resources and support, identification of most species should be required. Why? The answer is implicit in observations paraphrased from Woodwell (1974): If qualities of the environment that are essential for certain types of life are changed, the structure of natural systems will change. The species favored are those whose populations can respond most rapidly to the changes. These species are mostly small bodied, rapidly reproducing forms that can exploit altered conditions. Such modified conditions increase the frequency of rapidly reproducing pest and weed species. When chronic disturbance of any kind changes the structure of natural ecosystms, populations of hardy resistant organisms characteristic of impoverished sites increase, food chains are shortened, and the capacity for support of all life is reduced.

Until more adequate systematic services and financial support are available—but as a short term expedient only—precise identification in applied work could include appropriate representatives in at least the functional categories of estuarine and coastal organisms listed in Table 2. Which species of plants and animals should be emphasized would depend on the mission of each investigation. The unsolved problem in this approach is the serious difficulty of defining what constitute representative organisms!

On the surface it might seem that the systematics of estuarine species might be less complex than that of marine groups because their number is proportionately less. Potentially, however, the problem is as, or more, complex, because the estuarine systematist has to be prepared to deal with, not only marine species which normally move in and out of estuaries, but those which may extend their ranges, be introduced by storms, coastal birds, or human activities, or float down rivers and streams during stormy periods.

Why Not Ignore Undescribed Organisms?

Is it necessary in both basic and applied biological work to consider those organisms which man has not yet named and described, and which, therefore, are unavailable for consideration until taxonomically treated?

Some (Ehrlich, 1961; Raven et al., 1971; Sokal, 1970) would argue (a) that we should restrict identification and classification to those organisms which are of actual or potential value, and (b) that to insist that it is necessary to name every living organ-

Table 2.—Functional groups of estuarine and coastal organisms which should be considered for identification in the assessment of the impact of pollution.

Groups	Examples
Commercial and sports organisms: used and potentially useful	Phytoplankton, seaweeds, sponges, corals, bivalves, gastropods, cephalopods, polychetes, decapod crustaceans, fin fishes, sea turtles, porpoises, dolphins, whales (see Shapiro, 1971).
Organisms associated with commercial and sports organisms	Competitors, mutualists, commensals, predators, and food organisms (see Henry, 1966); disease and parasitic organisms: viruses, bacteria, fungi, sporozoans, ciliates, trematodes, cestodes, nematodes, copepods, isopods, gastropods (see Sindermann, 1970).
Organisms poisonous or potentially poisonous or harmful to humans as food, in swimming, or in other recreation	Animals that bite or sting: sharks, sting rays, manta, barracuda, moray eels, cat fishes, scorpion fishes, toad fishes, sea bass, sea lions, killer whales, tridacna clams, sea nettles, cone gastropods, octopuses, sea urchins (see Halstead, 1959); poisonous to eat: shellfish which have consumed toxic dinoflagellates, poisonous sharks and rays, moray eels, poisonous fin fish (see Halstead, 1959); parasites: amebas, trematodes, cestodes, nematodes; disease organisms: viruses, bacteria, fungi, yeasts (see Cheng, 1967).
Organisms fouling surfaces of estuarine structures	Algae, fungi, protozoans, sponges, coelenterates, bryozoans, annelids, bivalves, tunicates (see Woods Hole Oceanographic Institution, 1952).
Organisms over, on, and in areas to be, or being used for mining, dredging, filling, waste disposal, power plants, oil and gas exploration and development	Most lower plant, invertebrate groups: plankton, nekton, epifauna and epiflora, infauna, meiofauna.
Organisms blocking screens of power plant intakes and other marine operations	Primarily nekton: fin fish, some crustaceans; macroscopic algae.

ism in order to complete the job of systematics, ignores the necessity for judicious sampling in our efforts to understand the universe. This point of view, unfortunately, overlooks the critical question "How are actual and potential value determined?" It also dismisses the significance of biological classification which is intended to provide a framework on which to arrange all levels of all available biological information. Clearly, substantial gaps in the framework leave voids in the content within which relationships can be expressed (Heywood, 1973).

Others, whose point of view I share, feel that the primary job of exploring the flora and fauna of the earth's surface desperately needs doing because the natural resources of the globe are being destroyed at a fearful rate and hundreds of potentially invaluable species will be wiped out of existence even before they are made known to science, much less analyzed for potential utilization (Fosberg, 1972; Keck, 1959; Mayr, 1969; Steere, 1971). Many of these species may be found useful horticulturally, agronomically, and economically, as food, forage, timber, fiber, pulp, medicine, ground cover, and so on. (Keck, 1959). For example, (a) the sperm whale is nearing extinction with loss of its natural product, sperm oil, but botanists discovered that an obscure desert plant called jojoba produces a liquid wax which may function as a substitute; (b) a little-known beetle produces a medically important drug, cortisone, in amounts equivalent to the adrenal glands of 1,300 cattle; and (c) prostaglandins, important hormones available in very limited natural supply, occur in quantity in a soft gorgonian coral in the West Indies (Evans, 1973). Furthermore, we do not know whether certain organisms are essential to the continued functioning of the ecological processes on which our continued tenure on the planet depends (Fosberg, 1972)—and we dare not risk not finding out!

To complete the task of identification of all species will require the labors of several more generations. Considering the limited number of specialists, we must take it for granted that a large part of the majority of the kinds of plants and animals will remain unsampled, unnamed, and unclassified for decades to come (Mayr, 1969). At present probably one-third of the living species of fishes remains unknown. Our inventory of invertebrate animals remains seriously incomplete. Insects are far and away the most numerous in species, and the least known. Oceanic and estuarine plant and animal life is very incompletely understood. Knowledge of the species of bacteria, viruses, yeasts, and fungi is sparse, a serious deficiency considering their great economic importance and the vast number of species (Steere, 1971).

Many well-known plant and animal species have passed into extinction in the last 150 years (Steere, 1971), and thus are irreplaceable. It is postulated that literally thousands of species will become extinct in the next generation in all parts of the world as a result of the growing human population, pollution, and habitat destruction (Mayr, 1969; Terborgh, 1974; Uetz and Johnson, 1974). Raven et al. (1971), even more pessimistic about the survival of species, doubt that even 5 percent of the world's undescribed organisms can be added to our inventory before the currently undescribed 80 percent or so of the world's organisms become extinct.

Woodwell (1974) vividly summarized the trends and the consequences of extinctions:

> This is the pattern of life now, slow, progressive, cumulative and unidirectional as species are eliminated; the pattern is already widespread, perhaps worldwide in some degree. It leads, not to a clear crisis, a cataclysm, but to the slow erosion of the quality of environment; to the loss of fish in fisheries, to the accumulation of pests, plant and animal; to the gradual erosion of the

capacity of environment to stabilize water flows, to provide clean water, fiber and food, to hold and recycle nutrients on the land. It leads to accumulation of biotically impoverished zones almost without notice, zones that are progressively less capable of supporting life, including man, and it leads to a steady increase in requirements for human intervention in the basic function of environment: more dams and more pesticides.

I am convinced that all organisms on the globe have a functional role, directly or indirectly, of consequence to man. In spite of the enormity of the task, we must proceed with a sense of urgency in the systematic exploration of the world's biota in order to salvage at least the most critical species prior to their possible extinction.

HOW ADEQUATE ARE TAXONOMIC IDENTIFICATION PUBLICATIONS AND SERVICES?

The lack of inventories of systematic specialists, publications on identification, and taxonomic identification services constitue a major bottleneck in the application of systematics to the serious problems of environmental deterioration. In the United States we are fortunate, indeed, that an active, dedicated group of biologists has recently organized nationally as the Association of Systematics Collections with the primary goals of improving (a) the condition of biological systematics collections as a national resource, and (b) the quality and efficiency of systematic services associated with these resources (Irwin et al., 1973). It is regrettable that several years may elapse before these services will be available at the level of performance at which they are so badly needed.

Systematic Specialists

No current lists of systematists and their fields of specialization exist. An international directory of botanical specialists appeared in 1958 (Roon, 1958), and another on zoological taxonomists of the world was published in 1961 (Blackwelder and Blackwelder, 1961). Regrettably, these are now somewhat out-of-date. As a result one must generally rely on word of mouth for this information, a not very efficient means of distributing scientific data.

Identification Resources

Taxonomic information on a limited number of estuarine and coastal marine plants and animals is generally available and reasonably complete, but that on most others is scattered and coverage is

Table 3.—Status of taxonomic publications for identification and classification of macro- and meiofauna in the estuaries and continental shelf of the middle eastern United States. (References are not listed in the literature section of this paper).

Macrofauna
Porifera: deLaubenfels (1949), Hartman (1958), and Wells, Wells and Gray (1960) are good sources, but no comprehensive guide is available.
Coelenterata, Hydrozoa: Fraser (1944) is thorough but difficult to use, and species are often difficult to distinguish; Nutting (1900–1915) is better but doesn't cover all families; many species need redescribing.
Coelenterata, Anthozoa: no complete source.
Rhynchocoela: Coe (1943) is excellent, but some knowledge of internal morphology is required.
Annelida, Polychaeta: some groups, such as the distinctly errant families, are covered well in sources like Pettibone (1963), but there are serious difficulties with some sedentary families, for example, the Cirratulidae and Capitellidae. Day (1973) is also helpful.
Sipunculida: the recent paper by Cutler (1973) is very helpful.
Mollusca: the second edition of Abbott's (1974) book is indispensible since it lists all molluscs found off this coast and gives references to descriptions.
Crustacea, Cirripedia: the unpublished preliminary report by Zullo (1963) is helpful, but is relatively unavailable.
Crustacea, Mysidacea: Tattersall (1951) is thorough, but difficult to use; a handbook by R. Wigley is in preparation.
Crustacea, Cumacea: no complete source is available; a handbook by L. Watling is in preparation.
Crustacea, Tanaidacea: no complete source is available.
Crustacea, Isopoda: the handbook by Schultz (1969) is excellent for identification.
Crustacea, Amphipoda: Bousfield (1973) is excellent for the more commonly found species; some of the older monographs are needed occasionally.
Crustacea, Stomatopoda: Manning (1974) covers the few local species.
Crustacea, Decapoda: Williams (1965, 1974) are both excellent.
Bryozoa: papers by Osburn (1912) and Maturo (1957) are very useful; however, a comprehensive guide is much needed.
Echinodermata, Asteroidea: no complete source is available, but Gray et al. (1968) is helpful.
Echinodermata, Ophiuroidea: no complete source.
Echinodermata, Holothuroidea: Deichmann (1930) is very good.
Urochordata: the monograph by Van Name (1945) is excellent, but difficult to obtain.
Meiofauna
Protozoa: Borror (1973) covers the genera of ciliates. While there is a profuse literature on Foraminifera, no comprehensive key exists; there are no complete sources for other protozoan groups.
Platyhelminthes: no complete source.
Gastrotricha: no complete source, taxonomy is unsettled.
Kinorhyncha: American species largely unknown, and generally overlooked.
Nematoda: no complete source; many species from American Atlantic waters have been described, but the nematode fauna from mid-Atlantic shelf waters is virtually unknown.
Annelida, Archiannelida: no complete source.
Annelida, Oligochaeta: identification of species is difficult but has been made considerably easier by the papers of Brinkhurst and Jamieson (1971) and Cook and Brinkhurst (1973).
Crustacea, Ostracoda: many scattered papers, but there is no complete source.
Crustacea, Copepoda: harpacticoid copepods from the mid-Atlantic continental shelf are not well documented.

seriously incomplete and spotty. Especially lacking are taxonomic monographs on major and minor taxa; illustrated keys, manuals, check lists, and atlases; and authoritatively identified, representative, accessible collections of organisms, their photographs, and resource literature (Carriker, 1967).

Selection of some taxonomic groups for study is too often guided by chance rather than by careful choice on the basis of the greatest void in knowledge. In other groups, systematists have not had the time or assistance to prepare syntheses, even though much of the technical information may be at hand. Then there are whole phyla, especially among marine invertebrates, for which there are no authoritative specialists. Moreover, early stages in the life history of the biota are generally less well-known than adults; least known are the micro-, meio-, and small megabenthos. These several groups therefore pose insurmountable systematic barriers to most ecologists. The absence of systematic information has been circumvented by some biologists by giving potential species arbitrary codes until such time as these organisms can be investigated systematically. This expedient, however, excludes the value of positioning species in the classification scheme for interpretative analysis based on relationships.

The seriousness of the problem of inadequate identification resources is emphasized by Chace (reproduced in Schmitt, 1953, Appendix A) and Watling and Maurer (1974).

Chace in a revision of his list on the status of the systematics of recent invertebrates other than insects, included comments on 44 major taxa. The following observations are representative.:

> . . . identification difficult or impossible without living material; more specialists greatly needed; virtually impossible to obtain identifications; the only experienced taxonomist is too busy with teaching and administration for identifications; large collections still awaiting identification; few publications; the only specialist is retired; poorly known groups, need much more study; the only specialist just deceased; intensive studies now in progress; group fairly well covered, but world monograph needed; coverage reasonably good except for Atlantic species.

Clearly, prospects for identification were not promising.

The data compiled by Watling and Maurer (1974) indicate that a grave problem still faces benthic ecologists in establishing monitoring programs, and that progress in systematics has been slow since the preparation of Chace's list (Table 3).

Watling (1974) observed that most groups (the Mollusca, for example) have received systematic coverage that is usually inversely proportional to their ecological importance but directly proportional to their size, color, and ease of handling! Though some improvement is evident in the number and quality of identification publications, the level is still far from what is required and must be achieved in a reasonable time if we are to meet the needs of pollutional ecology and other fields of biology.

In some regions of the United States the serious void in identification publications is being partially filled by series of illustrated identification manuals prepared aperiodically by collaborating systematic specialists as resources and time are available.

One of these, the "Marine Flora and Fauna of the Northeastern United States," is well underway and provides a model for the organization of similar series on other coastal regions where none exists (Carriker, 1974). The first manual was published in 1973, and since then five additional ones on coastal plants and invertebrates have appeared, printed for the advisory board of the series by the National Marine Fisheries Service in NOAA Technical Reports. Some 80 systematic specialists in the United States and a few abroad are contributing manuscripts. Much of the work on the "Marine Flora and Fauna" is done as a "labor of love," support, if any, coming from whatever source is available.

A second series, "Manuals on Marine Organisms," dealing with tropical Atlantic American fauna, being prepared by G. L. Voss and F. M. Bayer and associates, University of Miami, is representative of biota of the southeastern United States. Two guides, written for use by non-specialists in the fisheries and environmental fields, have been published, and several more are in preparation. Basic information on poorly known groups is published in another series, "Fauna Caribaea."

A third series, "Biota of Freshwater Ecosystems," sponsored by the Environmental Protection Agency with the assistance of the Smithsonian Institution, is a valuable series of identification manuals on North American organisms prepared by specialists (Smithsonian Institution, 1972–1973). Although not directly applicable to coastal waters, the set is an important supplement in the identification of freshwater organisms floating into estuaries from streams and lakes. To date 11 manuals have appeared in print and others are in preparation.

Systematic Services

For many kinds of organisms one investigator easily obtains enough specimens in a short time to swamp several identifiers for months. Moreover, there are many more requests than can be filled for service identifications for ecologists, amateurs, public health officials, and those conducting stream and

forest surveys; for lists of organisms for impact studies; and for the needs of pollution assessment and monitoring. These, and other economically oriented service needs, have far outstripped the capacity of taxonomists and their assistants to cope with the flood of requests (Irwin et al., 1973). In spite of the fact that many state governments, experiment stations, or agricultural schools employ personnel to provide identification services of species common in their geographic areas, the number of professionally capable systematists is still small. The federal government maintains national identification services for several groups of economically important organisms, such as insects and related taxa, and parasites of domestic and other animals. Some of the federal services provide in-house identifications only, while others serve outside agencies and the general public. Even with these services, nonetheless, identifiers for many taxonomic groups are quite unable to keep up with the current demand for determinations, much less provide for prospective future needs. Some sorting centers have been created for marine organisms, but none makes specific identifications, and lag time is exasperating (Michener, 1970).

In addition to current requests, most taxonomists are faced with a great accumulation of unworked, undetermined specimens which have piled up for years (Schmitt, 1953). Because systematists who are willing to function in a service role are invariably overworked and under-assisted, they are unable to cope with the demands on their time. The needs of other biologists are thus often poorly served, and available comparative collections are frequently inadequately curated for proper study (Irwin et al., 1973).

Traditionally, identifications have been provided free of charge by taxonomists or organizations willing to make them. This practice is patently unfair, and has contributed to the lack of technical assistance to systematists, to the prolonged delay in obtaining identifications, and to the unattractiveness of the service function. It is gratifying to report, however, that this trend is shifting, and some grants are now including funds for taxonomic services.

Most critical in the long view, after all is said and done, is the fact that the service role often prevents systematists from getting on with the urgent research of preparing the basic floras, faunas, and monographs—the very foundation of the service function.

There is thus unquestionably a strong basis for the alarm expressed, especially by organismic biologists, over the service role of systematics to the nation and the future of the field of systematics itself! It is clear that a strong, coordinated, long range, national plan is urgently required.

Members of the Association of Systematics Collections (ASC) have already formulated such a plan called "America's Systematics Collections: A National Plan" (Irwin et al., 1973). This stresses the importance of systematics collections to science, society, and education, and outlines an approach, carefully developed by the newly organized community of systematists, for the recognition and development of systematics collections as an important national resource and service.

Specific goals of the ASC include: (1) management of the national inventory of specimens and associated documentation in museums and herbaria to insure a) permanent conservation of specimens, b) ready access to them and their documentation, and c) space, facilities, and library resources; and (2) addition of new specimens and associated information. Specific service-related aims include (1) make available upon demand specimens or taxon-related information in a variety of useful forms, (2) enable incorporation of specimens and associated data in an information management system, and (3) enable ready access to specimens themselves and to associated documentation and library materials. The ASC is moving ahead to implement these goals. Some of their activities, carried out through a series of ASC Councils, include: (1) identifying systematics collections of importance as national resources; (2) developing standards for systematics collections; (3) implementing electronic data processing in collection management procedures; (4) developing more effective use of systematics collections in the study and resolution of problems affecting the quality of the environment; and (5) developing technical training programs for professional service personnel and their placement.

A major emphasis of the ASC is correct identification of species to indicate environmental changes and their effects on human welfare. The association accordingly includes in its plan a survey of public and private agencies to determine actual or potential availability of resources to support, among other systematic activities, contracts for specific identification services.

Systematic resources in the United States of importance in estuarine biological work also include collections of living specimens. The American Type Culture Collection, for example, is a national identification center in Rockville, Md., which for a fee identifies live viruses, bacteria, fungi, and protozoans. The organization is now establishing a national computerized microbiological strain data center

which will permit investigators to compare microbiological data with that at other centers in the country. Another important national research resource is the Culture Collection of Algae at Indiana University, Bloomington. Identification services are not provided because of lack of personnel, but living type cultures of algae are available for a nominal charge.

Non-Specialists and Identification

The non-specialist is usually able to identify and classify only those species which specialists have already described, named, and reported in the scientific literature. Because of the frequent difficulty of use of the original systematic reports by nonspecialists, systematists synthesize the original literature into a form which is more readily applied in identification and classification. These syntheses take the form of illustrated manuals, check lists, taxonomic monographs, and general systematic books. An excellent example of the last category is the recent volume by R. T. Abbott (1974) on the marine molluscs of the Atlantic and Pacific coasts of North America. Others are E. L. Bousfield's (1973) fine publication on the shallow water gammaridean amphipods of New England, and Light's manual on the intertidal invertebrates of the central California coast (Smith and Carlton, 1975).

Because closely similar species may be confused, it is highly desirable that the non-specialist confirm his preliminary identifications by comparing specimens with correctly identified specimens in museum and herbarium collections. This procedure is all the more important as similar and closely related species not listed in publications readily available to non-specialists may be overlooked.

For careful research, comparison alone may not provide the necessary authoritative confirmation. In this case the assistance of a specialist, or an assistant closely associated with the specialist, should be solicited. Identification is not always a simple matter of identifying one standard form of individual. In a series of individuals from many localities, complications may be introduced because of such modifying factors as individual, sexual, seasonal, ontogenetic, and geographic variations, as well as the possibility of intergradation with neighboring species (Schmitt, 1953). Moreover, introduced and immigrant species may be present that answer to the same criteria in a key as do local species. Hedgpeth (1975) informs me that over 50 non-native species occur in San Francisco Bay alone!

Because of the taxonomic complexity of many organisms, and the consequent danger of misidentification, voucher specimens should be made available, preferably in museums and herbaria, whenever possible. These insure that the value of ecological, behavioral, physiological, biogeographic, and other biological work based on identifications will not be reduced due to questions about inaccuracy of determination of the organisms involved (Irwin et al., 1973).

TRENDS IN SYSTEMATICS—SYSTEMATISTS ENDANGERED?

Unquestionably the degree of success of the service function of systematics in future years will be determined by the health of the field of systematics today. It is thus important to review the current state of the discipline.

In Darwin's time systematists enjoyed a high reputation. The turning point in disfavor came about the turn of the century, not because of the work of systematists but because other fields of biology seemed more promising (Hedgpeth, 1961). Systematics then received a substantial stimulus with the creation of the National Science Foundation in 1950. Although increased funding resulted in a multiplication of systematic research, subsequent financial support from all sources has been insufficient to keep pace with the needs of systematics in either basic or applied areas. Consequently, the current resources of the field are inadequate to meet not only present national service needs, but much less the needs of the future.

For one thing, decreasing numbers of students are attracted to careers in systematic biology. The reasons, not hard to find, contribute to the low number of trained systematists: a tight job market and reluctance of many university departments to hire systematists, overshadowing of systematics by such fields as ecology and behavior, reduced amount of available support for graduate students in the form of fellowships, and general deemphasis of systematics in graduate curricula (Humes, 1974). In fact, systematists have been all but excluded from many of the best biology departments in this country (Wilson, 1971). As a result, many teaching systematists are trying, with little success (Steere, 1971), to leave academia and move into museums which seem to have become the last bastion of defense for systematics—which is wrong! (Pawson, 1974).

Because systematics does not occupy a prominent position in most educational institutions, much of the systematic research conducted in the country is done in fragments of time snatched between ad-

ministrative or teaching duties by biologists whose major responsibilities are nonsystematic.

In spite of the fact that the potential worth of systematics to society is now greater than ever, only a handful of graduate university departments in the United States and Canada are now strong in systematics. These departments have to be associated in some way with research collections to conduct their teaching and research; and whereas several state universities and colleges used to maintain museums with biological research collections, few do now because of funding problems. Default in this area has thus led to surrender of important regional collections to the United States National Museum. The result of this drift in collections has been to remove resource materials from new scholars to some degree and to widen the split between educational opportunity and young biologists who could participate in this discipline. Many who become taxonomists, therefore, do so in spite of these difficulties, or are self-trained (Mosquin, 1971; Watling, 1974; Williams, 1974).

Systematists at the doctoral level require many years of training. Most rarely wish to devote full time, or even part time, to the service aspects of systematics, particularly since such services are not professionally satisfying and have seldom been financially compensated. Hopefully, with growing national recognition of the importance of systematics, more systematists will be encouraged to participate in service oriented investigations; the resulting service resources (keys, manuals, monographs, computer programs, and so on) then being turned over to technical taxonomically trained assistants to carry out the service activities. It is important that the significant role of taxonomic assistants be fully recognized, and that they become the major working force in taxonomic service centers under the direction of professional supervisors.

Since the number of pure research positions in systematics is limited and most systematists earn their living as teachers, curators, members of identification services, or in other branches of biology, the borderline between systematists and other biologists has blurred. This is providing opportunity in systematics for biologists of varied interests (Mayr, 1969). Many ecologists are a good example. Because of the scarcity of systematists, identification has fallen increasingly on the ecologist, and as a consequence some have become highly proficient in the systematics relating to their field of research. The blending of systematics with closely related disciplines, both as pure science and in its application, augurs well for the future of systematists. So does the growing appreciation of the correct image of the modern systematist; that is, one who concerns himself not only with preserved specimens in collections, but who also works in the field and in the laboratory studying whatever phase of morphology, physiology, ecology, behavior, biogeography, and life history contributes to a fuller quantitative understanding of the likenesses, differences, groupings, and evolution of the species of his specialty (Turner, 1974). Mayr (1969) notes that the systematist has every reason to be optimistic about the future of his field. The laudable efforts of the Association of Systematics Collections may help to materialize this optimism. For the moment, though, we have to agree with Redfield's (1958) observation for an earlier period, that "The line of advance in taxonomic knowledge is held by a perilously thin force of specialists."

With growth and strengthening of biological research, has come increased usage of systematics collections. Researchers in increasing numbers are visiting the few systematics collections in their specialties. The number of loans of specimens similarly has grown. Burgeoning collections and loan requests are outstripping staff capabilities. Nearly every major institution responsible for major systematics collections is crowded, and space is inadequate for effective research and efficient care of specimens. A further depreciating factor is the prevalent shortage of clerical and subprofessional help, especially in institutions having ambitious systematic programs and limited finances (Schmitt, 1953). It is thus no surprise that systematics collections are deteriorating. To all of this must be added the factor of inflation which results in lowered income.

Summary.—Even though requirements for identification of estuarine and coastal organisms have greatly accelerated, present trends in systematics appear bleak indeed.

Relative to the population growth of the country, (a) there are fewer highly trained systematists; (b) there is a significant decline in the number of practicing taxonomists (Higgins, 1974); (c) there is less financial support for them and for systematic activities in all institutions; (d) there are fewer positions and (e) training opportunities; and (f) there is a scarcity of journals in which to publish (Gosline, 1974).

It is increasingly difficult to have organisms identified; capable systematists are so much in demand that they give service only to a selected few, generally with preference to those who furnish specimens which remain in their collections or new species

that are to be described (Allen, 1974; Tarzwell, 1974).

The fate of biological collections in colleges and universities depends to a deplorable extent upon the research emphasis of the moment. As responsible personnel move to other institutions, collections are left in grave danger, or they are turned over to the large museums and herbaria of the country. These changes invariably occur without increase of their supportive resources. As a consequence these large institutions are increasingly charged with carrying out and supporting systematic biology. At least one danger of this trend is the weakening of instruction in systematic biology and thus the balanced and orderly development of the science of biology itself (Schmidt, 1952).

Progress has been made in some aspects of systematics, but serious setbacks have occurred in others. For example, there has been increased emphasis on the taxonomy of both phytoplankton (especially nanoplankton) and zooplankton (especially larval forms and their developmental stages), but the systematics of nematodes which appear to be the most abundant of the metazoans and are probably the most diverse in number of species, has hardly progressed from the status of 19th century science (Murphy, 1974).

There is a definite, healthy trend toward numerical taxonomy and phenetics to define species assemblages, but a marked increase in casual identifications in applied systematics often by ecologists engaged in biomass and community structural studies (M. Abbott, 1974).

Finally, Steere (1971), writing about institutions which house biological systematics collections, reports that in the previous three years, operating expenses almost doubled, and endowment returns and contributions halved. Predictably this has led to substandard salaries, deterioration of personnel strength (because of unchanged staff size in the face of swelling collections and increased demands for service), reduction of activities, and deferral of expansion. This situation is totally unacceptable if modern biology is to develop in these institutions and they are to fulfill their service roles in applied systematics!

Water Quality Legislation and Systematics

Water quality legislation assures "the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife" in any body of water into which, for example, thermal discharge is to be made (Federal Water Pollution Control Act, Amendments of 1972, Public Law 92-500, Section 316(a); see also Section 102(a) and Hedgpeth, 1973). The legislation implies the need for identification and classification of organisms, both target and non-target species, involved in analysis of the biological impact of pollutants. By way of example, consider the voluminous reports which have appeared on such subjects as ecological effects of pesticides on non-target species (Pimentel, 1971) and data on water quality criteria (Batelle, 1971; NAS-NAE, 1972). As of this date, however, this emphasis of the federal legislation has not resulted in conspicuous financial support for systematic work on any of the important taxa.

It is certain that requirements for identification of biota will not only continue, but will increase, because of the escalating concern of many agencies and the public with problems and issues of environmental quality. Emphasis at the moment reflects needs anticipated and created by the energy crisis. Other issues concern mercury, lead, asbestos, PCB's, NTA, and oil spills (for example, see Eisler, 1973). It is certain new concerns will emerge in the future. Specimens in museums, herbaria, and live culture collections, and those made to meet immediate needs, will continue to provide baseline data prior to and following environmental alterations (Allen, 1974). Organisms involved must thus be correctly identified; if not, costly mistakes can occur. It is consequently with dismay that one reads: "The taxonomic level to which animals are identified depends on the needs, experience, and available resources" (Weber, 1973).

Adequate environmental assessment cannot be obtained without the resources of systematics collections. The Environmental Protection Agency has made a preliminary effort to contribute toward improving the quality of data upon which environmental decisions are based (see, for example, the identification manuals of Correll and Correll (1972) and the Smithsonian Institution (1972–1973)), but unfortunately these efforts are giving way increasingly to mission oriented and mandated activities (Allen, 1974). Also note that monitoring of biota was demanded in licensing by the Atomic Energy Commission, but there has been no visible increase in the demand for systematists resulting from these requirements (Higgins, 1974).

Man is an organism, of course, but since he does not generally submit to being used as a barometer of environmental conditions, he delegates this responsibility to other forms of life. This is a weighty responsibility and necessitates that the taxonomic

position of his substitutes be solidly established for purposes of comparison and prediction!

CONCERNS AND CONCLUSIONS

Basic and applied environmental research and its application to such practical problems as pollution, have grown far more rapidly than the supporting base of systematic biology. As a consequence of this deficit and the conditions described in this paper, systematists find themselves in a paradoxical quagmire. Thus, though willing, they are unable adequately to fill the needs of environmental biologists, pollution scientists, and others for systematic services. The concerns may be summarized as follows:

1) There is an increasing shortage of systematists to handle and supervise identifications and classifications; as a consequence, more and more inadequately trained persons are performing this service;
2) There is an insufficient number of systematists to conduct the basic research necessary to produce the systematic tools required in applied systematic biology;
3) Identification and classification aids are inadequate or insufficient for most taxa, and are entirely missing for others;
4) The number of taxonomically well-trained technicians to relieve systematists of the work of routine identification is grossly insufficient;
5) Compensation to systematic specialists for taxonomic services is generally nonexistent, a lack foreign to professional services in other scientific and engineering fields;
6) There is a total absence of current directories of systematic specialists, identification service centers, identification aids, and a national computerized storage-retrieval system for the systematic resources of the nation;
7) Both young and experienced systematists find it increasingly difficult to obtain positions in their fields of specialization;
8) Young people are unable to obtain training in systematics in most colleges and universities where the field receives decreasing emphasis and support;
9) Valuable representative collections from environmental studies are discarded or lost, and no voucher specimens are reposited in museums and herbaria for future reference;
10) Environmental agencies have paid lip service to the importance of systematics in environmental work, but have not provided the financial support necessary to help prepare systematics more effectively for this role;
11) Most museums, herbaria, and living collections receive inadequate financial support and are understaffed, with the result that systematics collections are receiving insufficient care, are deteriorating, and the service function is suffering—the problem being seriously compounded by inflation.

The most pressing systematic service needs at the moment are (a) well trained technicians, (b) systematists with the time to supervise them, (c) identification aids, and (d) funds to help systematists carry out their functions and elevate systematic biology to the position where it can more effectively contribute to science and to society.

It is imperative that everything possible be done, not only to conserve the human and material systematic resources already existing, but also to support and encourage further development of these resources in a hospitable climate, appreciatively recognizing the economic and intrinsic worth of their contributions. The tasks facing systematists are unquestionably monumental and long-term.

RECOMMENDATIONS

The following recommendations are offered to maximize the service role of biological systematics in the assessment of the effects of pollution on the biological utilization of estuaries and coastal waters in the United States:

(1) A major, national, coherent force working in behalf of systematics in the country is the Association for Systematics Collections. The ASC estimates that it will cost $63.3 million in the next five years to effect its national plan for the conservation and development of systematics collections as a national resource and service (Irwin et al., 1973). The various councils of the ASC are now preparing proposals for financial support to carry out the plan. We urge federal and private agencies to look with favor on these proposals. A unique feature of the ASC plan is its integrated national character, a necessary attribute to provide systematic services in any estuary or coastal area in the country. Support must go to aid in the development of aspects of the plan as a whole, rather than for parochial units of restricted regional interest. In view of the increasing number of persons who are making professional identifications without the advantage of adequate training, we further urge the ASC to establish a roster of persons qualified to make service identifications in the various groups of organisms.

(2) In the face of growing, critical, environmental problems in estuaries and coastal waters, institutions and agencies will accelerate their search for

financial support through grants and contracts to attack these problems. In the interest of aiding the service aspects of systematics, we urge funding agencies to look favorably upon requests involving: (a) compensation to systematic specialists in the private sector for identifications and confirmation of identifications; (b) proper curation of biological research collections resulting from environmental and other broad investigations to serve as voucher specimens; (c) services for taxonomically trained assistants; (d) enlargement of identification service centers in museums and universities, including training of taxonomic technicians to handle specimens from major pollutional surveys; (e) fellowships for advanced training at those major museums and universities having faculties in evolutionary biology, in combination with ecology, comparative physiology, or other organismic biology; (f) support of systematists in governmental agencies and elsewhere dealing with whole organisms, giving them time to develop their systematic specialties and to contribute to the upgrading of practical systematics through the preparation of basic and applied systematic resources.

(3) A serious void in identification publications is comprehensive illustrated identification manuals. Accordingly, we urge funding of a comprehensive, illustrated, coastal flora and fauna series for each major coastal region of the United States which would invite the talents of the community of systematists in the preparation of each series. A minimum of $25,000 will be needed per year for each of the three series already in progress on the east coast, and at least similar amounts will be necessary for a new series for the gulf coast, and another for the west coast—a total of $725,000 for the first five years.

(4) A number of persons of considerable competence as systematists, many at the doctoral level, unable to obtain positions either in museums or in universities, are now supervising environmental departments of engineering and power companies. Their training as systematists has thus been a waste to society. We endorse Hedgpeth's (1975) recommendation that each power and engineering company hire a systematist specializing in a different taxonomic group to provide identification service for a reasonably natural geographic region. Thus on the Pacific coast one power company might provide service for polychaetes, another for crustaceans, and so on. Nominal fees should be charged for the service.

(5) A major long-term research effort, to be measured in decades, is still required before the full extent to which systematic knowledge can significantly aid in the identification and control of pollution is known. Moreover, completion of the task of identification of most undescribed species will require several more generations. We thus urge that adequate support for systematics be sustained for many years to come, allowing the maximum return on the investment in terms of basic systematic knowledge and taxonomic services.

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ACKNOWLEDGMENTS

I would like to express my gratitude to the following persons for valuable assistance in the preparation of the manuscript: Marie B. Abbott, R. Tucker Abbott, William D. Burbanck, Robert P. Higgins, Arthur G. Humes, Raymond B. Manning, Frank J. S. Maturo, Jr., Andrew McErlean, Margaret S. McFadien, Daniel Merriman, Allan D. Michael, Donald G. Murphy, Joel O'Connor, David L. Pawson, Waldo L. Schmitt, Carl N. Shuster, Clarence M. Tarzwell, Ruth D. Turner, Leslie A. Watling, Roland L. Wigley, Robert T. Wilce, and Austin B. Williams.

Contribution No. 103, University of Delaware, College of Marine Studies.

BACTERIA AND VIRUSES—INDICATORS OF UNNATURAL ENVIRONMENTAL CHANGES OCCURRING IN THE NATION'S ESTUARIES

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ABSTRACT

Microorganisms are useful indicators of alterations in the natural environment. As presently employed, however, "indicator organisms" such as fecal coliforms and total coliforms have severe limitations. Other organisms have been proposed in recent years as potential indicator organisms, viz., streptococci, clostridia, and pseudomonads. The indicator organism concept is reviewed and recommendations for future studies are made. In particular, detection, isolation, and identification of viruses, effects of pollutants on the natural microbial flora, and reevaluation of microbial indicators are critical areas requiring research.

INTRODUCTION

The bacteria, yeasts, and fungi naturally present in waters and sediments play an essential role in the mineralization and cycling of nutrients necessary for normal plant and animal growth. A variety of microorganisms may appear in given ecosystems from time to time because of the ubiquity of many bacterial species; in general, the normal flora of the aquatic habitat is distinguishable from bacteria associated with warm-blooded animals and man. Moreover, the numbers and types of bacteria present in the natural habitat are generally in balance so that conditions are stable within recognizable, normal levels. When abnormal conditions occur, changes in the microbial populations will ensue. For example, with pollution from domestic or farm animals, influx from wastewater treatment plants, and so forth, the number of bacteria of animal or human origin increases. Hence, a hazard to man may develop.

Estuarine eutrophication and coastal pollution pose increasingly serious environmental problems. Nutrient loads in estuaries are based on watershed characteristics, influent stream concentrations, and overall watershed management policies. The role of microorganisms, in particular the bacteria, is to break down the dead organic material and wastes so that organic nutrients necessary for plant growth are provided and organic wastes are removed by mineralization. Thus, the role of the bacteria, yeasts, and fungi, is, simply stated, to keep the wheel of nature turning by recycling complex organic and inorganic materials. Nutrients, in moderation and in proper balance, permit normal algal productivity which, in turn, supports animal life.

Changes in environmental conditions may cause more subtle effects on the normal microbial flora, leading to such conditions as increased disease in many resident fish species or unpleasant anoxic conditions arising from hydrogen sulfide production.

INDICATOR ORGANISMS

In the case of microorganisms, indicators are usually considered in relation to human health risk. The most common forms of water-borne human disease are caused by bacteria excreted from the intestines of man and warm-blooded animals. Fecal contamination is recognized as dangerous. However, pathogens normally are present in small numbers and are difficult to culture and identify. Thus, the more easily identified organisms that are commonly and specifically present in feces serve as indicator organisms. The most widely used are the so-called coliform bacteria, with *Escherichia coli* or the less specifically fecal coliforms being tested for in most cases.

Thus, for well over a hundred years, bacteria have been used as indicators of unnatural or undesirable environmental conditions, mainly as indicators of human health hazards, i.e., warning signs that potential human pathogens may be present. In 1885 Escherich described the bacterial species he believed to be characteristic of human feces and, therefore, an indicator of fecal pollution. The bacterial species of Escherich is now classified in the

Escherichia-Enterobacter group and comprises, with other species, the complex now referred to as the coliform group. These organisms are to this day the indicator microorganisms employed by authorities in determining rate and extent of pollution from domestic sewage.

Eijkman, in his studies carried out over 70 years ago, recommended an elevated temperature incubation test that gave a positive reaction with fecal coliform organisms and a negative reaction with those of non-fecal origin (Eijkman, 1904). The Eijkman test procedure is the basis of the EC test, which is widely used to detect fecal coliforms. Unfortunately, no test is available for differentiating coliforms of human versus animal origin. The Eijkman test, however, does indicate fecal coliforms. The generally accepted principle is that the presence of fecal coliforms indicates the potential presence of disease-producing microbes (Kabler et al., 1964).

Present methods depend on enumeration of lactose-fermenting bacteria by an MPN procedure and further biochemical testing to establish whether these organisms are coliforms, fecal coliforms, or *E. coli*. General standards have been developed to relate the quantitative occurrence of these various types to presumed acceptable or unacceptable levels of fecal contamination (Hoskins, 1934; Geldreich et al., 1962).

Streptococcus spp. known as enterococci occur in the gut of warm-blooded animals and man. Studies of streptococci in water and sewage have shown that these organisms can serve as indicators of fecal pollution. The sanitary significance of fecal streptococci has been clarified and these bacteria can now be efficiently and accurately enumerated in water samples. All of the species or types of fecal streptococci found in feces of human beings and animals can be isolated from sewage and water contaminated with sewage, including estuarine and coastal waters (Bartley and Slanetz, 1960). A definite relationship between the densities of coliform bacteria and enterococci in sewage has long been known (Litsky et al., 1953). In fact, an increase in the coliform index is generally followed by a predictable increase in the enterococcus index, with a direct relationship between the numbers of coliform bacteria and enterococci. Unfortunately, enterococci are found elsewhere in nature, occurring on plants, in dairy products, and so forth, so that sources of these microorganisms must be carefully scrutinized at each time of assessment (Mundt, 1964; Geldreich et al., 1964). Because of their resistance to adverse conditions, enterococci are fairly widespread. Therefore, one must expect, and deal with, higher "natural" levels. The isolation of enterococci from nature has been enhanced by improved methods and media for isolation. For example, azide dextrose broth, used as a presumptive test, and ethyl violet azide broth, a confirmation test, permit two to three orders of magnitude improvement in the isolation and identification of enterococci (Litsky et al., 1955).

A variety of pathogenic microorganisms may be present in the feces of warm-blooded animals, viz., *Brucella*, *Salmonella*, *Shigella* spp., *Mycobacterium tuberculosis*, *Pasteurella*, *Leptospira*, *Vibrio cholerae*, *Entamoeba histolytica*, and various enteric viruses. Most of these genera noted are present in the feces of diseased animals. Hence, the main factor involved is the occurrence in a population and shedding of the microorganisms into water via feces. Thus, the density of pathogens in the aqueous environment is affected by a variety of factors: (a) type and degree of sewage treatment; (b) ability of microorganisms to survive the effects of antibiosis, predation, and chemical nature of the water; (c) dietary habits and socio-economic status of the community; (d) the prevalence of specific disease in the community; (e) endemic conditions in the human and animal population; and (f) existent carrier rates in the population (Brezenski and Russomanno, 1969). Therefore, the introduction of specific pathogens via sewage or runoff into estuaries and coastal waters is not constant, but rather tends to be intermittent. With the uneven microorganism distribution in water, coupled with effects of dilution and environmental parameters, such as temperature and salinity, the density and distribution of pathogenic microorganisms has resulted in the search for indicator organisms, as opposed to looking for the individual pathogen. More accurate and simplified techniques for the isolation of *Salmonella* have been developed in recent years so that confirmation of *Salmonella* can be achieved (Cheng et al., 1971). Despite the fact that detection methods for *Salmonella* have been improved, they are still likely to be missed.

Where the bacteriological quality of the water is poor, fecal coliforms and salmonellae can be isolated. Often in estuaries and coastal waters, wild fowl will contribute to the salmonellae population load (Strobel, 1968). Salmonella, in recent years, have been directly isolated from polluted tidal estuaries, but at low percentage recovery, i.e., 1 to 200 fecal coliforms (Brezenski and Russomanno, 1969). Nevertheless, the prevalence of *Salmonellae* is greater than previously thought to be. Factors, such as salinity, temperature, and others associated with the saline environment cannot be depended upon to eliminate such pathogens. Greater survival of salmonellae and fecal coliforms in shellfish, when

the water temperature reaches below 5°C, has been observed by several workers. Clearly, isolation of salmonella from a polluted marine environment has been improved by application of better techniques and enrichment media (Grunnet et al., 1970). However, these pathogens, because of the complexity of the methods required for isolation and identification, are not ordinarily searched for in an analysis of water quality.

More recently the anaerobic bacteria, i.e., the *Clostridium* spp., the acid-fast bacteria, i.e., *Mycobacterium* spp., and yeasts have been suggested as indicators of sewage pollution. Selective procedures for these organisms are now being developed. Rapid isolation procedures are not yet available. The major *Clostridium* species in polluted marine sediments have been shown to be *Cl. perfringens*, *Cl. bifermentans* and *Cl. novyi*, these representing 58 percent of the population and reflecting the representation of Clostridial spp. in sewage (Matches et al., 1974). *Cl. perfringens*, because it is more sewage related, appears to be of useful sanitary significance in cases of high pollution levels. Similarly, the densities of yeasts in sewage and in polluted waters have been shown to be high, with *Candida tropicalis*, *Trichosporon cutaneous*, and *Rhodotorula* spp. potentially serving as useful indicator organisms. In fact, the pathogenic yeast, *Candida albicans*, has been shown to be a good indicator of recent human sewage pollution (Ahearne, 1973).

Clearly, bacteria and viruses serve as indicators of health in estuaries and coastal waters. Many studies over the years have shown that under natural conditions, i.e., in areas untouched by the activities of man, a relatively stable total microbial population occurs in water and sediment. Under conditions of imbalance, microorganisms will achieve very high total numbers and frequently under such conditions will cause foul odors, unacceptable bottom or sediment conditions, slimes fouling fish nets and floating objects, and depletion of dissolved oxygen in the water, thereby affecting fish and other organisms. In balance, microbial populations perform a necessary function in estuaries and coastal waters. Out of balance, the viruses, bacteria, yeasts, and fungi become nuisances and threaten the health of humans and of desirable plants and animals.

Microbial quality changes in estuarine and coastal ecosystems may prove to be valuable indicators or "early warning systems." However, in the case of ecosystem components, such bacterial groups as the sulfur bacteria, iron bacteria, blue green algae, and so forth, have not yet been sufficiently studied to be easily isolated and identified. Hence, their use as indicator organisms is limited, particularly since ecosystem monitoring on a long-term basis, which would help to clarify the role of these organisms, is lacking.

Improved Detection of Indicator Organisms

Detection of indicator organisms has improved considerably in recent years with the application of methods such as membrane filters (American Public Health Association, 1971; Presswood and Brown, 1973) and development of techniques employing nonfluorescing membrane filters and specific fluoresceinisothiocyanate-labeled antiserum (Guthrie and Reeder, 1969). Fluorescent antibody methods for detection of *Streptococcus faecalis*, *Escherichia coli* and *Salmonella* spp. are now available, improving speed for processing samples over conventional water quality tests, without loss of reliability (Abshire and Guthrie, 1972).

In the case of the fluorescent antibody, techniques pertaining to the pathogens are more advanced than for the indicator bacteria, although fluorescent antibody methods for the detection of fecal streptococci have been developed. Recent work has demonstrated the applicability of the fluorescent antibody technique employing commercially available antisera (Pugsley and Evison, 1974). This, no doubt, will usher in a new era for the use of fecal streptococci in conjunction with other indicator organisms.

Problems with the Indicator Organism Concept

Confidence has been decreasing in the significance of the coliform group as an indicator of fecal pollution. In recently reported epidemics, pathogens have been isolated from waters which, based on coliform standards, should have been safe. *Salmonellae* have been isolated from water supplies containing less than 2.2 coliforms per 100 ml. A number of such incidences where *Salmonella* and enteric viruses have been isolated from waters containing few detectable fecal coliforms have been documented (Bonde, 1974; Dutka, 1973; Fugate et al., 1975). The ability of coliforms to multiply in nutrient enriched receiving waters has been observed. The sanitary significance of fecal coliforms in the environment has been considered by a number of investigators (Geldreich, 1966). Convincing evidence has been presented, showing that viruses are more resistant to chlorination than bacteria. Rates of growth and die-off of both *S. typhimurium* and coliform organisms have been found to be different under

varying environmental conditions. Furthermore, conditions causing large reductions in coliforms do not always show correspondingly reduced numbers of *Salmonella* (Dutka, 1973).

The shortcomings of the coliform group as an indicator of pollution have led to the increased desirability of employing the streptococci as indicators of recent and dangerous pollution. The fecal streptococci rarely multiply in water, as some of the coliforms have been found to do. Thus, they offer some advantages as indicators of recent fecal pollution. Also, it has been suggested that domestic sewage pollution can be differentiated from animal wastes, land runoff, and storm water pollution by fecal coliform-fecal streptococcus ratios (Geldreich, 1972).

In general, the fecal streptococci are more resistant to the natural water environment and to purification processes than the coliforms or fecal coliforms. At points distant from the original source of pollution, the fecal streptococci are often the only indicators of the fecal nature of the pollution. Studies have shown that the survival of fecal streptococci parallel the survival of enteric viruses better than the coliforms (Cohen and Shuval, 1973). It has been suggested by some workers that the fecal streptococci may, in some cases, provide a better estimate of the probable virus content (Cohen and Shuval, 1973).

Dissatisfaction with the fecal coliform and fecal streptococci has led to a search for other, better indicators. Coliphages (bacterial viruses) have been suggested as indicators of sewage pollution. However, no consistent relationship is observed between coliform and coliphage levels (Hilton and Stotzky, 1973). Although the complexity of the bacteriophage method and time required before final results are available discount their use as indicators of fecal pollution of water, bacteriophages can serve well as models for detection of enteric viral pollution of water and in epidemiological applications (Scarpino, 1974).

Pseudomonas aeruginosa is slowly gaining favor as an indicator of water quality, especially as an indicator of potential upper respiratory tract infections (Foster et al., 1971; Kenner and Clark, 1974).

Relatively recent approaches to estimating bacterial quality of water are uptake of phosphorus, using radioactive phosphorous (Khanna, 1973), and assay for fecal sterols for water pollution indication. The intestinal bacterial flora is associated with production of characteristic fecal sterols discharged in feces (Martin et al., 1973). Fecal compounds, in particular coprostanol and cholesterol, thus, have been examined and a coliform-coprostanol relationship has been reported. However, a consistency in the relationships from the data presently available has not been observed (Dutka, Chan and Coburn, unpublished data). Fecal sterols may well prove useful in the future as pollution indicators, but the method will require substantial developmental research before proper evaluation and application are possible.

Natural Estuarine Microbial Communities

Microorganisms autochthonous to a given estuarine system play a fundamental role in mineralization and cycling of nutrients. Estimation of the microbial biomass comprising the natural flora of estuaries can be accomplished by direct counts and morphological observations using acridine orange staining and epifluorescence illumination of the bacteria collected on non-fluorescent membrane filters. Measurement of the activity of microbial populations directly in the environment can also be accomplished using methods such as uptake rates of radioactively-labeled organic substrates (Wright, 1973). The use of ATP to measure standing crops of microorganisms is widely accepted (Holm-Hansen, 1969) and the ATP method offers promise as an indicator of microbial activity.

The role of bacteria in the detrivore food chain is only beginning to be understood (Hamilton, 1973; Rosswall, 1973). Effects of pollutants on these natural processes require extensive study since very little information, relatively speaking, is presently available.

Deterioration of Coastal and Estuarine Waters

Many studies have shown that coliform bacteria introduced into tidal, coastal, and deep sea waters disappear rapidly. A large number and variety of factors have been shown to be involved in the die-off of coliforms, especially *Escherichia coli*, in seawater. Dilution, bacteriocidal action of seawater, grazing by zooplankton, adsorption on estuarine and coastal sediments (Ketchum et al., 1952), salinity, effect of heavy metals in seawater (Jones, 1963; 1971), lysis of coliforms by indigenous marine bacteria such as *Bdellovibrio* spp., and bacteriophages (Mitchell et al., 1967; Carlucci and Pramer, 1960), low nutrient levels in seawater (Jannasch, 1968), daylight (Pike et al., 1970) and temperature have been offered as explanation for the die-off of *E. coli* in seawater and for the absence of fecal coliforms in ocean locations far from land. Nutrients have a marked beneficial effect on the survival of *E. coli*

in seawater. Some nutrients, such as cysteine, very likely act by chelating metal ions in seawater (Scarpino and Pramer, 1962).

Furthermore, above certain BOD levels, viz. 1–10 mg/l initial BOD, seawater will temporarily lose its toxicity and the maximum bacterial density becomes dependent on the initial BOD. In fresh seawater with BOD levels of 10 to 120 mg/l, the relationship between the log of the maximum bacterial densities and the initial BOD appears to be linear. Thus, by themselves, total and fecal coliform bacteria may not be reliable indicators of the degree of recent fecal pollution in seawater because, given sufficient nutrient levels, the bacterial density will increase (Savage and Hanes, 1971). Growth of coliform bacteria, isolated from soft-shelled clams, in estuarine water has been demonstrated (Lear, 1962). The conclusion which can be drawn from the data available is that the various factors in seawater which, under clean, unpolluted conditions, will act to eliminate coliforms from estuarine and coastal waters cannot be depended upon in waters receiving heavy nutrient input. In fact, increases in coliform populations will occur and it is possible that survival of pathogens may be enhanced.

A signal to this effect is the relative ease with which antibiotic-resistant coliforms can be isolated from estuaries and coastal waters (Colwell and Sizemore, 1974; Feary et al., 1972). Many of these bacteria have been shown to harbor R factors carrying multiple antibiotic resistance which could be transferred to sensitive *Salmonella typhimurium*, *Shigella dysenteriae*, and *E. coli*. Of serious concern is the fact that these bacteria are isolated from shellfish waters. Furthermore, chloramphenicol-resistant bacteria of fecal origin may pose a particular health hazard, with reference to R factors which carry resistance determinants to chloramphenicol. Transfer of chloramphenicol resistance to *Salmonella typhi*, a water-borne organism, or to *Vibrio parahaemolyticus*, would make treatment of typhoid fever or *V. parahaemolyticus* food poisoning more difficult. It would appear, therefore, wise for sanitary quality measurements of shellfish waters to include estimates of chloramphenicol-resistant fecal coliforms. An important conclusion of the work on antibiotic-resistant types found in rivers, estuaries, and coastal waters is that the R + *E. coli* comes from urban sewage (Smith, 1970).

The coincidence of infectious disease in fishes with stress caused by temperature, eutrophication, sewage, industrial pollution, and pesticides has been documented (Snieszko, 1974). Estuaries and coastal areas affected by pollution expose the fish in these areas to frequent stresses, i.e., unfavorable or fluctuating water chemistry, organic pollutants, and so on (Wedemyer and Wood, 1974). If the occurrence of stress coincides with the presence of pathogenic microorganisms, outbreaks of disease will occur. Interestingly, in treated sewage the number of coliforms is reduced, but in the bacterial population, the coliforms appear to be replaced by *Aeromonas* which multiply in the slime lining of the pipes carrying the sewage (Heuschmann-Brunner, 1970). The quantity of *Aeromonas* in water can be related to the degree of pollution. Many *Aeromonas*, *Pseudomonas*, and *Vibrio* species are bacterial fish pathogens. Marine fishes in areas exposed to pollution have been reported to show exophthalmus, open external sores, epitheliomas, and papillomas. In fishes experimentally exposed to the polluted water, skin hemorrhages, opaqueness of eyes, and blindness were observed. In terminal stages fluid accumulated in the body cavity and internal hemorrhaging occurred. *Aeromonas*, *Pseudomonas* and *Vibrio* were isolated from the diseased fishes. All strains isolated from marine fishes were halophilic (Snieszko, 1974). The conclusion, therefore, is that there is a relationship between incidence of disease in fish populations and pollution of estuarine and coastal waters with domestic and industrial sewage. A weakening of the fish, with subsequent invasion by microorganisms, causing disease and/or death, appears to be related to pollution. Unfortunately, in several incidences, widespread distribution and prevalence of *Aeromonas* spp. was noted with a general lack of coliforms and other sewage-related organisms. Recovery of "almost pure cultures of *Aeromonas* spp." from the effluent of sewage-treatment plants has been observed, particularly in estuarine water (Snieszko, 1974). It can only be concluded that the incidence of diseases of aquatic animals in which *Aeromonas* plays an important role will increase. The additional factors of low dissolved oxygen, high temperature, and pollution by chemicals, such as pesticides, petroleum, and heavy metals, must contribute to outbreaks of infectious diseases of aquatic animals. In fact, fishes although long considered important animals for assaying water pollution are becoming valuable indicators of the environmental health of bodies of water. The Chesapeake Bay is highly polluted by every type of waste. Some of the waste causes eutrophication, with increase of bacteria and algae and oxygen depletion. Fish kills are a frequent occurrence, particularly in summer months. Epidemics causing massive mortalities of fish in Chesapeake Bay have been recorded (Snieszko, 1974).

Deterioration of estuarine and coastal waters can be detected in increased nutrient input, with concomitant rise in indicator or noxious microorganisms,

and in increased prevalence of disease among components of the natural biota, especially the commercial fishes.

PROBLEM AREAS

Indicator Organisms

The value of the coliform test as the principal microbiological criterion for sanitary quality of estuarine and coastal waters is a controversial issue. *E. coli* (Type I) appears to be the most reliable indicator of fresh fecal pollution, rather than total coliforms. It is questionable whether coliforms can be regarded as true indicators of fecal pollution at all (Bonde, 1974).

Results obtained from Most Probable Numbers (MPN) measurements have not been sufficiently examined to determine the variability of MPN data. Results obtained from the same area at short intervals of time, i.e., hours, need to be examined critically. If such results are extremely variable, the value of monitoring MPN on daily or weekly intervals is highly doubtful.

There is no single test for the coliforms. Since most of the *E. coli* strains ferment lactose, with production of acid and gas, this characteristic is useful in presumptive, quantitative determinations. Unfortunately, recent work in microbial genetics has shown that not all strains of *E. coli* are able to ferment lactose. Furthermore, this characteristic is not restricted to *E. coli* and may be found in other related bacteria often present in polluted waters. Hence, false presumptive tests are not infrequent. Another difficulty is that coliforms may be affected by their stay in water or sediment and may grow slowly or even lose some of their "typical" characteristics; hence, difficulties in isolation, identification, and enumeration are encountered.

Relatively high occurrence of "false-positives" in MPN estimates of fecal streptococci in estuarine and marine waters has been reported (Buck, 1969). In heavily polluted marine waters, false-positives are not a problem. Mainly in estuarine or marine waters of low or varying salinity, all positive tubes need to be examined microscopically for the presence of nonstreptococcal forms. In fact, an indigenous population of false-positive microorganisms may exist in coastal waters.

Indicator microorganisms other than coliforms also pose problems. *Pseudomonas* spp. are widely distributed in nature. Determinations of *P. aeruginosa*, a known pathogen for man and warm-blooded animals, have been suggested for estuarine waters where high water temperatures and available nutrients can allow growth of this microorganism. *Aeromonas*, fecal streptococci, *Clostridium perfringens*, *Bifidobacterium*, *Bacillus*, *Thiobacillus*, and direct demonstration of *Salmonella* spp. have all been suggested as indicator organisms. A conclusion that can be drawn from the data available in the literature is that all of these indicators should be considered and that more than one indicator organism should be examined. That is, two or more indicator species should be enumerated to improve the reliability of estimating pollution and/or human health hazard.

Survival of pathogens and indicator organisms in estuarine and marine water and sediment is an important problem. Fecal streptococci are supposed to indicate recent fecal pollution and *Cl. perfringens*, because of its spore-forming capacity is considered to be highly resistant, hence of longer survival in nature. Coliforms and *Salmonella typhi* often survive in sediment much longer than in the overlying water. The distribution in mud reflects the effluent flow pattern in the overlying water, with much higher densities of coliforms found in mud. Salmonellae can be isolated from bottom sediments with far greater frequency than directly from the overlying water (Van Donsel and Geldreich, 1971; Hendricks, 1971). However, it should be pointed out that the mud-water interface is not a static system. Currents, storms, seasonal turnovers, and dredging operations can shift sediment, scattering it widely. Such redistribution creates the additional hazard of recirculation of older pollutants in lower layers of sediment. This, coupled with the fact that sediment bacteria are part of the diet of tubificid worms and other sediment-residing biota, provides a mechanism of concentration and transfer of coliforms and potential pathogens among the indigenous fauna (Wavre and Brinkhurst, 1971).

Survival of fecal coliforms and fecal streptococci varies according to season. During the summer months, fecal coliforms can survive slightly longer than fecal streptococci. During the autumn months, survival is about the same and in spring and winter, fecal streptococci may survive much longer than fecal coliforms. Within bodies of water, thermal transitional zones may create bacterial gradients, especially along inshore areas, acting to confine nutrients, bacteria, and nuisance algal growths to the nearshore area. One of the potential hazards of such a thermal barrier, notably in estuaries, is that effluents discharged into a nearshore area are not diluted, as would occur under normal conditions, but are contained by the barrier effect of a thermal bar (Menon et al., 1971). Factors influencing the survival of enteric indicator organisms have been

summarized in a recent symposium (Gameson, 1974).

Viruses

During the past decade, there has been worldwide interest and concern that significant levels of viruses are being transmitted through potable and recreational water. Conclusive evidence for the transmission of enteric viruses via this route lies in outbreaks of infectious hepatitis, where sanitary practice or water treatment has broken down or contaminated shellfish have been consumed (Berg, 1973). The opinion that viruses in estuaries and coastal waters pose a threat to human health can be justified by the following facts. Most enteric viruses are more resistant than indicator bacteria to inactivation by water disinfectants. Infectivity tests have shown infection can be caused by one poliovirus TCD_{50} unit (Berg, 1971).

A consistently high endemic level of infectious hepatitis has occurred in the U.S. with the concomitant knowledge that the infectious hepatitis agent is relatively resistant to inactivation in the aquatic environment. Sporadic outbreaks of nonbacterial gastroenteritis suspected of being waterborne have occurred, coupled with a most likely high endemic level of the disease. Finally, surface-water domestic pollution has increased to the point that direct recycling of wastewater and reclamation of estuarine waters is very nearly a reality in the case of some water systems (Akin et al., 1974). Clearly, the danger of water transmission of enteric viral disease is great enough to warrant the more careful consideration viruses are now receiving.

More than 100 new human enteric viruses have been described in the 25 years since the advent of viral propagation techniques using tissue cultures (Scarpino, 1974). All of these enteric viruses are known to be excreted in quantity in the feces of man, including enteroviruses (poliovirus, coxsackievirus, and echovirus), infectious hepatitis, adenoviruses, and reoviruses. Viruses do not multiply outside of living susceptible cells; hence, human enteric viruses can be expected to decrease in numbers with time, even when nutrient levels are high. However, the major question is how long will human enteric viruses survive when discharged into estuarine and coastal waters. The presence of enteric viruses in estuarine and ocean waters has been amply documented (Metcalf and Stiles, 1965, 1968; Shuval, 1970). Survival of enteroviruses in the marine environment has been demonstrated by a number of investigators. Enteric virus survival in estuary and ocean waters has been shown to be dependent upon temperature, biotic flora, degree of pollution, and virus type (Metcalf and Stiles, 1968). A virucidal activity in seawater has been demonstrated, but it may have only a minor role in inactivating enteric viruses in estuarine and ocean waters.

The importance of enteric viruses is not in their numbers but in their infectivity (Scarpino, 1974). One tissue-culture dose is considered to constitute an infectious dose, meaning that only a few virus particles are needed to initiate an infection in a susceptible host. Thus, it has been necessary only to show the presence of viruses in water, with less emphasis placed on quantitation. Since enteroviruses of human origin in estuarine and coastal waters may remain infectious for a significant period of time, depending on environmental factors, it has been suggested that enteroviruses themselves may serve as the most valid indicator of pollution. Poliovirus and infectious hepatitis virus (hepatitis A) have both been suggested as indicator agents. Unfortunately, the data show that virus inactivation or die-off in marine water is unpredictable. Marine water with the same salinity collected from the same site on different days may show wide variations in viral survival patterns (Atkins et al., 1974).

Thus, the major effort, at present, in research on water-borne viruses is in development of sensitive methods for recovering viruses from marine waters and for determining survival times of these viruses in different types of water (Berg, 1974; Malina and Sagik, 1974). Monitoring of estuarine and coastal waters for enteric viruses will eventually be commonplace. For the present, routine monitoring of potable water and wastewater for enteric viruses is yet to be accomplished on a large scale.

Methods available to detect viruses in water are many and varied, including gauze pads for pre-concentration *in situ*; membrane filter adsorption; electrophoresis; ultrafiltration hydroextraction; precipitation, adsorption-elution; separation with two-phase polymers; soluble ultrafilter; and ultracentrifugation (Foliguet et al., 1973; Hill et al., 1971). The main problem in virus isolation, namely, the large volumes of water that must be examined (up to 100 liters per sampling) appears to have been overcome (Hill et al., 1972; Sobsey et al., 1973). A virus concentration unit, designed by Melnick and co-workers, is being used for virus monitoring in water supplies throughout the world. At the International Conference on Viruses and Water, Mexico City, June 9–12, 1974, it was clear that adequate methods for concentrating large volumes of water for enterovirus monitoring are now available.

In general, the methodology for isolation and

characterization of indicator viruses is in the developmental stage. Perfecting these techniques is the main concern of research work underway. Still unknown is how widespread viruses are in estuaries and coastal waters. Also, the incidence of viral diseases transmitted via polluted estuarine and coastal waters is not known. Some new methods for viral detection may improve and speed up virus isolation and characterization, viz., the use of Australian antigen as a marker for hepatitis B virus. Australian antigen has already been isolated from clams contaminated by untreated sewage from a coastal hospital (Mahoney et al., 1974). Other such markers may be discovered as research on the enteroviruses progresses. Survival of viruses in estuarine and coastal waters remains to be fully clarified. There is no doubt but that research to answer these questions must be done.

Alteration of the Natural Microbial Flora

An aspect of the ecology of estuarine and marine waters, about which next to nothing is known, is the alteration of the natural microbial flora induced by introduction of pollutants. That bacterial species in an estuary demonstrate seasonal cycles has been shown (Kaneko and Colwell, 1972). It is logical to assume that microorganisms associated with the biota, water, and sediment of estuaries and coastal waters are in a delicate balance.

Introduction of sewage, industrial wastes, or other pollutants will first impact upon the microflora. The microbial response is very rapid, within hours or days, at the most. A shifting of microbial species and physiological types will occur in response to the influx. Species selection will take place, as, for example, the dominance of *Aeromonas* spp. in sewage effluent. The effects of such shifts in the microbial populations are completely unknown. Yet, they may result in fish kills, clam mortalities, marsh grass diseases, and noxious odors and appearance of the receiving waters.

Microbial populations may well prove to be the "fine-tuning" mechanism of the estuarine and marine ecosystem. However, not enough research is being done to provide the necessary information. Since new methods for automating microbial data collection and processing by computer have been developed (Oliver and Colwell, 1974), such questions are no longer so overwhelmingly complex and, in fact, can be answered, if the proper research effort is provided.

Efforts of Specific Effluents on Microbial Populations

Recent work has shown that in areas receiving petroleum, pesticide, or heavy metal discharges, the microbial flora contains significant petroleum-degrading, pesticide-metabolizing, or heavy-metal-mobilizing bacteria (Walker and Colwell, 1973; Nelson and Colwell, 1974). Similarly, in estuarine and marine waters receiving sewage, pulp mill, or canning wastes, the heterotrophic bacterial populations increase significantly. The point which can be made is that these respondent bacterial species may be usefully employed as markers or indicators of such pollution. Little research effort has been directed explicitly along this line. It is suggested that such efforts may prove substantially rewarding for those concerned with chronic, low-level environmental impact, where the grosser symptoms of environmental deterioration are not seen.

Implicit in such an application is, however, that extensive and relatively complete knowledge of the natural microbial flora is available. Alas, this is not so and, again, the plea which is now nearly a cacophonic chorus, sung by botanists, zoologists, limnologists, oceanographers, and, now, microbiologists, is that baseline studies must be done. Numerous studies and countless analyses have been discarded due to the lack of the necessary baseline data. It is of great importance that the yardstick for measurement is available and that yardstick is baseline data. Unpolluted environments, as well as polluted ones, must be studied to determine the natural balance of the autochthonous microbial species, so that impacts of pollutants can be assessed.

Microbial species may act to concentrate such pollutants as heavy metals, or serve to pass polluting materials on through the food chain, especially in the case of filter or detritus feeders and protozoans (Wavre and Brinkhurst, 1971; Burke, Small, and Colwell, in press).

EVALUATION OF PRESENT STATUS AND RECENT ADVANCES

There have been improvements in the methods of isolation and characterization of the indicator organisms of human health significance, namely, *E. coli* Type I, *Salmonella*, Enterococci, Clostridia, and Enteroviruses. However, the concept of a single indicator organism as the measuring unit for the health of an estuarine or coastal ecosystem is in dispute. The indicator organisms are each subject to the vagaries of environmental and biological param-

eters, so that consistent results in survival studies are not always obtained. Enteroviruses appear to be the better indicators of human health hazard but the technology of virus isolation and characterization is cumbersome and complex, too much so for routine monitoring applications.

Indicator organisms for measuring the health of the ecosystem itself are not available although biological assessment of water pollution has been studied in Central Europe, comprising a saprobity system (Bick, 1963). Estuarine and marine microbial ecology, in fact, is still in its infancy, relative to molecular and medical microbiology. Understanding of the role of microorganisms in the food chain is sparse and unreliable, at best. Too few competent experiments have been done and much too little information is available on this very important aspect of the estuarine and marine ecosystem.

It is obvious that microorganisms are expected to degrade the pesticides, heavy metal compounds, petroleum, and other pollutants entering the estuaries and coastal waters. Yet, embarrassingly little is known about the mineralization of these pollutants *in situ*. It is not only the pollutants that are of great concern, but the overall processes naturally occurring in any body of water, as well as the processes that occur when any perturbing force acts on the system. Bodies of water are in constant flux. Clearly our knowledge of processes mediated by microorganisms is far too meager for appropriate management considerations. Furthermore, the realization that microorganisms may actually concentrate carcinogens in petroleum or convert relatively harmless petroleum components to carcinogens is only just now being perceived by both scientists and management.

The improved methods for coliform, enterococci, virus, Clostridia, and other microorganism isolation and characterization are directly applicable for use in the estuarine environment. The more recent work on isolation of bacteria and viruses from estuarine and coastal water provide improved methodology useful in assessing the human health hazard extant in the nation's estuaries and coastal waters.

The information now being obtained on microbial mobilization of heavy metals, pesticides, detergents, petroleum, and other pollutants in estuaries and coastal waters will permit better assessment of the capability of such ecosystems to withstand the influx of such pollutants. One result may prove to be that the scope and magnitude of pollutants now entering certain of the nation's estuaries and coastal water regions are beyond the capacity of the indigenous microbial populations to mineralize them; hence, accumulations of residues of these pollutants may be building up, especially in the sediments at these sites.

FUTURE NEEDS

1. The indicator organism concept must be revised. For indications of public health dangers, combinations of indicator organisms should be employed, viz., fecal coliforms, enterococci and Clostridia, or fecal coliforms and enteroviruses, and others. The advantages and disadvantages of each indicator organism should be determined so that they may be applied more intelligently to environmental assessment.

Additional indicator organisms must be sought which will point to ecosystem alteration. These may be sulfur bacteria, iron bacteria, *Aeromonas* spp., or physiological groups, such as mercury-mobilizing bacteria or detergent-degrading microorganisms. Clearly, a need for ecosystem indicators is developing rapidly as the demand for environmental impact assessment increases.

Further research to determine the variability of Most Probable Number (MPN) of coliforms must be done. It is critical that the variability of this count be determined, especially for given sites at short intervals, i.e., hours, so that the value of monitoring MPN on daily, weekly, or monthly bases can be properly assessed.

2. Improved methods for virus isolation and identification are needed. Also, an understanding of virus survival in estuarine and coastal waters and sediment is required. More ominous are the human carcinogenic viruses. The presence, survival, and distribution of these viruses in estuarine and coastal waters must be assessed, particularly in those areas receiving pollutants which can act as co-carcinogens.

3. The impact of pollutants on the biota of estuaries and coastal waters must be determined. Reports concerning diseases of fishes near sewer outfalls and in the New York Bight area are disturbing. The chronic effects of sewage and industrial wastes on the microflora should be examined.

4. There is a serious lack of knowledge of the microbial contributions to the estuarine and marine ecosystems. The role of bacteria and other microorganisms in mineralization and cycling of nutrients is, at best, vaguely understood. A great deal of research work in both basic and applied microbial ecology is both necessary and urgent.

5. There is a genuine need for automation in our warning system. The use of fluorescent antibody lasers or other scanning devices may provide auto-

matic warning systems. With such systems, bodies of water may be studied around the clock so that deviations from the normal will be immediately detected. At the present time such deviations must be excessively large to be detected. Also, present methods require 24 hours minimum for detection.

Research must be done on the basic problems of rates of function of microbes in natural water. Since the rates of processes will affect the environment in which indicator organisms reside, this aspect of estuarine microbiology must receive proper attention. The bulk of the literature on aquatic systems deals with detection of indicator organisms of various types. Thus, the rates of microbially catalyzed processes involved in overall fluxes within aquatic systems, with time, have not been properly assessed. Clearly, insight into the operations of natural systems, particularly rate processes, will provide the predictive capability for eutrophication, i.e., establishment of systems that are undesirable for given reasons, whether they be economic, aesthetic, or ecological. Basic research, in this case, must precede the application, simply because the basic information is lacking.

RECOMMENDATIONS FOR ESTUARINE MANAGEMENT AND MONITORING

Unfortunately, the recommendations offered are the obvious, namely, to restrict or thoroughly treat domestic and industrial wastes entering the nation's estuaries. Increased nutrient loads are resulting in alterations in the microbial flora, with dominance of nuisance or pathogenic species. Control of petroleum discharge, as one example, into the estuarine environment is mandatory, if the commercial fisheries and natural wetlands are to be preserved.

Better control of land use, particularly retention of marsh areas and wetlands, is required. The wetlands may be the "natural septic system" of the estuaries and wider oscillations in the microbial populations may occur, if the natural "buffering effect" of the wetland areas is not preserved.

Finally, better use must be made of microbial indicators. They are, indeed, the "early-warning" system of the estuarine and coastal zones. More intelligent use of microbial indicators and a wider range of indicator organisms are needed. Early or chronic environmental effects may be detectable, if the microbial indicators are employed wisely and carefully. The estuaries and coastal zones of the nation are a valuable resource. It is both appropriate and timely that we harness the microorganisms. They may well tell us more about the environment than we had imagined to be possible.

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NATIONAL ESTUARINE MONITORING PROGRAM

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ABSTRACT

About 8,000 samples of estuarine molluscs were monitored for pesticide residues in the period 1965–1972. Residue trends and typical pollution situations are briefly described. Beginning in 1972, fish were substituted for molluscs. The basic needs for a continuing monitoring program are described.

INTRODUCTION

The importance of estuaries as either temporary or permanent homes for a majority of the commercially important fish and shellfish led to numerous early studies on man-induced changes that might affect the viability of these essential ecosystems. Preeminent among early studies were efforts to define the role of persistent pesticides which could collect in or pass through estuarine systems in surface runoff from rivers to the sea.

Concern about the potential threat of such pollutants in the marine environment was heightened by the occurrence of significant kills of fish and other non-target organisms in rivers and tidal marsh areas. That such kills were primarily accidental did not decrease the possibility that less obvious but not necessarily less significant events might be taking place as a result of chronic, low levels of pesticide contamination in estuaries. It was not known to what extent such contamination might follow the use of registered synthetic chemicals for the control of plant and animal pests in the surrounding drainage basin.

To assess the significance of persistent chemical residues it has been necessary to monitor their existence, magnitude, and seasonality in the environment. These field data, however, are useful only to the extent that the effects of these chemicals on the most sensitive life stages of significant species in the estuarine community are understood. Such information must be gained under controlled laboratory conditions and, regrettably, data of this type are still mostly fragmentary.

MONITORING BIVALVE SHELLFISH

However, laboratory studies of the eastern oyster and related molluscs had progressed by 1965 to the point that estuarine molluscs could be utilized as biological tools to monitor levels of synthetic chlorinated pesticides in the field (Butler, 1967). It was recognized that residue data from field samples would not be entirely comparable to data obtained in laboratory exposure tests. Still, within certain limits, field data would indicate the kinds of pollutants present and whether the levels of contamination posed a threat to the biota or to human health.

In July 1965, the Gulf Breeze Environmental Research Laboratory, at the time part of Interior's Bureau of Commercial Fisheries, initiated a comprehensive estuarine monitoring program in cooperation with other federal and state agencies in 15 coastal states.

Laboratory studies had shown that molluscs containing moderate pesticide residues were able to eliminate them in about two weeks in the absence of continuing pesticide pollution in their environment. Consequently, the monitoring program was organized so as to sample oyster, mussel, or clam populations, depending on species availability, at 30-day intervals for a proposed 5-year period in each geographic area. Such a program could identify not only seasonal pollutional patterns but also long-term trends.

In the period 1965–72, approximately 8,000 samples were analyzed for chlorinated pesticides. The data show that high levels of pesticide residues occurred in molluscs from estuaries associated with intensive agriculture, with large volumes of municipal waste discharge, and with industrial wastes from pesticide manufacturing plants. In many areas, there was good correlation between the fluctuating levels of residues in molluscs and the seasonal agricultural use of pesticides.

The overall picture of pesticide pollution in the nation's estuaries as revealed by the monitoring data was one of widespread contamination with

DDT and its metabolites but at generally low (non-toxic) levels. In a few areas DDT residues were large enough to suggest damage to the fauna but at no time was a human health problem indicated (Butler, 1973).

DDT residues in estuarine molluscs peaked in the 1968–69 period. Since then there has been a well-defined decline in the number of positive samples and in the magnitude of residues in nearly all estuarine areas. The decrease in the number of samples with detectable residues has been as much as 66 percent in areas where adequate data are available for evaluation.

Data Utilization

Monitoring data can be of inestimable value in detecting pesticide pollution sources and in developing the background information necessary for the efficient management of estuarine systems. In this monitoring program, three characteristic pollution situations have been identified and a description of them will illustrate the general usefulness of monitoring data in establishing some of the guidelines for regulating the manufacture and registration of pesticides.

The Rio Grande River Basin on the south Texas coast is an area of intensive farming of grain, citrus, and fiber crops. The subtropical climate permits multiple harvests annually. During the mid-1960's, the recommended farm use of pesticides in this area was about five times the amounts recommended in neighboring river basins. Oysters monitored in the Laguna Madre consistently contained DDT residues about five times that of oysters from other Texas estuaries. There is good evidence that the DDT residues in the food of speckled seatrout in this area were large enough to seriously interfere with the development of the young. It seems clear, in retrospect, that the registered use of persistent pesticides on Rio Grande Basin farmlands permitted the agricultural segment of the economy to work to the detriment of the local fishing industry. The continued use of DDT would have eventually eliminated the seatrout. The demonstrated need for pest control throughout the year in this area requires the substitution of non-persistent pesticides and biological controls which will not degrade the environment.

In southwest Florida, however, the use of DDT on maturing corn and sugar cane was distinctly seasonal. The runoff from farmlands in the Caloosahatchee River Basin contained sufficient DDT during the February-April period in 1967 and 1968 so that residues in local oysters were above the suggested 'action' level of 5 ppm. There is no reason to suspect this amount of DDT would be harmful to oysters themselves, nor are oysters preyed on in nature to the extent that tissue residues of this magnitude would be detrimental to some carnivore—including man. Nonetheless, these residues would prevent the oysters being legally harvested. In this instance, the use of DDT would have increased food production on the farm and reduced it in the sea. The cure, again, is the utilization of a less persistent pesticide either alone or in combination with some biological control of the agricultural pests.

The third situation was encountered on the Georgia coast. Oysters monitored in St. Simons Sound in 1967 were found to contain toxaphene residues, a pesticide not known to have been used in the area. Levels of toxaphene in water and sediments were high enough to admit the possibility of damage to many faunal groups. By the judicious placement of trays of oysters to monitor upstream sites, increasingly large toxaphene residues were accumulated, and the source of the pollutant was identified as a component of the waste in the effluent of a pesticide manufacturing facility. In this case, identification of the source resulted in a cleanup of the contaminated river bottom by dredging and the construction of evaporation ponds for onshore disposal of the toxic effluents.

MONITORING ESTUARINE FISH

The gradual decline in pesticide residues in monitored oysters during 1970–72 pointed out the need for a pollution yardstick that would be indicative over a longer interval of time. The monthly effort in monitoring oysters no longer seemed warranted in view of the continuing absence of positive samples in many areas. Both laboratory and field data had shown that, in contrast to molluscs, persistent pesticides accumulate with time in fish tissues. Older fish in polluted waters contain progressively larger pesticide or trace element residues than do younger fish. However, body residues in individual fish fluctuate unpredictably. This may be the result of dietary stress, spawning, or some other normal metabolic process.

Since fish are readily available, a revised program was initiated in 1972 to monitor them in all of the principal estuaries of the United States and its territories. Certain criteria were established to minimize unknown fluctuations. Sample size was increased to 50 individuals. Fish are sampled during their first year prior to spawning. This narrows the time in which residues could be acquired and avoids their loss in gamete production. Both particle-feeder and carnivorous fish are monitored in each estuary

to broaden the possibility of finding any pollutants present. During the first two years of the program, fish were monitored semi-annually to determine whether this was necessary or whether annual collections might be sufficiently informative.

Data Utilization

Analyses of the more than 1,500 samples of estuarine fish (37,500 individuals) monitored since July 1972 show that, in a majority of areas, DDT and other chlorinated pesticide residues have not been detectable. These data confirm the trend found in the molluscan monitoring and show that this type of estuarine pollution has indeed declined since the restriction in DDT use. The analyses show, too, that in those few estuaries where oysters were grossly polluted with DDT during the 1965–72 monitoring, yearling fish still have significantly large DDT residues. These residues, in the absence of the agricultural use of DDT, are presumably the results of recycling between the physical and biological substrates in the estuary. Or, alternatively, these residues may be the result of a continuing influx of DDT from up-river reservoirs in farm soils and river sediments.

It is apparent that the monitoring of estuarine fauna for persistent chemicals remains a continuing need. We must be in a position to gauge the effectiveness of legal restraints on the usage of known pollutants as well as be able to detect at an early date the appearance of other, perhaps still unknown, persistent chemicals that may be toxic to the biota or endanger man's food supply.

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A BRIEF ASSESSMENT OF ESTUARY MODELING— RECENT DEVELOPMENTS AND FUTURE TRENDS

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ABSTRACT

A brief, very informal, overview of estuarine modeling is presented; the great variety in estuarine environmental settings is exhibited with east and west coast examples. Typical problems confronted by the environmental scientist and engineer are discussed as well as some of the solution techniques employed to solve them.

INTRODUCTION

Estuaries are classified according to their vertical salinity and velocity profiles. For the simplest system, the profiles exhibit little vertical gradient in either parameter. More complex systems, such as fjords, can exhibit several changes in current direction in the vertical. Tidally affected rivers are also sometimes referred to as estuarine although oceanographers consider the estuary section of a river as that containing a measurable amount of salt.

There are many categories of "models." One distinction that is made here is between a *research* model, which an investigator may never document, and a *production* model, which might be implemented as a tool for management decision making (one popular catch-phrase underlying present day funding rationalizations).

Usually, no model is ever "final" since it is continually being revised as research develops. This is particularly true in estuarine systems where the dynamics of motion and dispersion of pollutants is highly complex. Added difficulties are encountered in the modeling of chemical and biological interactions. For best use, feedback between the modelers and the experimenters is required on a continuous and cooperative basis. All too often problems arise due to a lack of communication between the two groups, the modelers usually earning a reputation of the tail-wagging-the-dog.

Some would suggest that a bad model is better than no model at all since it does at least make an investigator think about the system, formalize his concepts, and make orderly what could otherwise be a chaotic field investigation. A good model will be a plus, of course, and can be the basis for the formal structure of a given estuarine research program. Suffice it to say that the field investigation designed with a sample scheme based on a "good" model has several orders of magnitude greater chance of bringing glory to its research team than to one that simply "samples."

PROGRESS IN THE LAST FIVE YEARS

Progress has been made in many aspects of estuarine simulation techniques in recent years. Theoretical development has been relatively slow except in the case of fjords, which have not been especially amenable to treatment due mostly to a lack of observational data. The so-called partially-mixed estuaries are also at an intermediate stage of development because of difficulties in treating vertical exchange processes. Theoreticians have been wrestling with this aspect for several years with little success. Indeed, many believe that a whole new theoretical approach will be required although it is difficult to envision a breakthrough which will lend itself to practical application in the near future.

In lieu of analytical solutions of differential equations, numerical solutions can be employed. The former method is used on simplified, general, representations of a given system. The simplifying assumptions employed allow investigations of many aspects of a system by, usually, rather formidable mathematical devices. When the devices aren't available or the system is too complex, then recourse to numerical methods is employed and the computer is used to carry out the relatively simple but extremely repetitive algebraic operations. There is a place for both methods; as a rule of thumb, research models

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are initially of the analytical variety while production models are an end product of research and employ numerical integration techniques.

Of considerably more interest to environmental scientists has been progress in analyzing chemical and biological interactions. While it is a necessity to simulate hydrodynamic processes in the best possible manner, so-called pollution problems usually are concerned with the input and effect of anthropogenic materials in the estuary or environment. If a pollutant is to be so considered then it must affect the human population either directly or through a certain chain of events. This chain may be initialized by the uptake of materials by a given organism not primarily utilized by man. Pollution, as defined by a government organization, for instance, may not be extant until several higher organisms have concentrated the substance to a detectable level—one which may or may not have deleterious effects on man. This kind of process has been known for many years, of course, but only recently have models been developed to the point of practical application, i.e., analysis or synthesis of these events.

Many of the models used today are variations of the rabbit and fox theme: a given population of rabbits is preyed upon by foxes; the fox population grows due to plentitude of food; both populations increase up to a point where the rabbits become scarce due to excessive predation. Eventually the fox population dies off due to starvation until a new equilibrium point is reached, and the cycle begins anew. Such events can be, and are, studied by mathematical models, each population being represented by a differential equation with appropriate growth and death rates, and so forth. Interaction between the two is accomplished in the mathematical treatment by coupling the equations through, e.g., a predation term. This explanation, while overly simplistic, illustrates many of the simulations of plankton growth and dieoff now analyzed through numerical experimentation. Many other reactions are also described in terms of this approach. It might be said that the easy part of the analysis is the mathematics; obtaining the right relationships, coefficients, their forms and dependencies is, and will remain, the difficult part of the problem.

SOME EXAMPLES

It will be assumed that the reader is unfamiliar with the models that have been developed for, or applied to, the systems to be described. What do these models do and, equally important, what don't they do?

East Coast

First, consider a simulation on a small (25 sq. nautical miles (n.m.)) well-mixed embayment on the east coast of the United States—Jamaica Bay, N.Y. This work was performed by Dr. J. J. Leendertse and his associates at the Rand Corporation with financial support mainly from the city of New York. As stated by Leendertse (1970) the study was "... intended as a first step toward providing a tool for a quantitative assessment of an environmental problem, i.e., the study of technical alternatives in the management of fluid waste discharges in well-mixed estuaries and coastal seas."

The work developed in stages—from representing tidal motion in the system, verification of hydraulics, simulation of dissolved oxygen and coliform concentrations, and a determination of the effect of storm water overflow on the system. The study is essentially complete; an evaluation of the benefits derived from this well-conducted effort in proportion to the costs incurred has not yet been made available. However, the project was designed to assess the effectiveness of several multi-million dollar sewage treatment schemes in the bay area. It is safe to conclude that the project costs are a minute fraction of the construction costs to be expended. A benefit/cost ratio greater than 1 can only be determined if construction cost savings were suggested by the model. It is quite possible that the model could project alternatives that would prove more costly than the initial plan costs but of more benefit to water quality. No doubt the economists have an appropriate ratio for this not unlikely event.

West Coast

As another example, a west coast study by Callaway, et al., (1969) is described. The system studied was the Columbia River from the Pacific Ocean to Bonneville Dam (146 miles, plus many islands and tributaries); rather vast and vastly different from Jamaica Bay. During low runoff periods, the lower 25 n.m. of the system are, by oceanographic definitions, estuarine. The problem here was based on a federal government decision "... to model the Columbia River system from the Canadian border to the Pacific Ocean for the purpose of evaluating existing and/or potential thermal pollution problems."

The first part of the study consisted of a description of the mathematical methods used, and the theory and documentation of the program. The second part described input and verification procedures, provided a test program, and gave examples

of output. The authors end with the following admonition: "If a slide rule will do the work don't use this model or anyone else's."

As a final example, the fjord system of Puget Sound is briefly discussed. This work is presently being supported by the EPA with Dr. Donald Winters, University of Washington, as principal investigator. This study is more complex than the two just mentioned, due in part to the lack of, and difficulty in obtaining, observational data upon which to develop theory. It is more comprehensive in that it is a grant objective to demonstrate ways in which such models can be used in the numerical assessment of biological activity in fjords. To date, the project has determined several important features concerning nutrient limitation and the effect of light penetration on plankton growth (Winters, et al., 1975). In addition, it has provided hydrodynamic input (Winters, 1973) to a commercial production model of parts of the sound.

FUTURE TRENDS AND NEEDS

Most of the major needs relating to simulation models of estuarine phenomena do not concern modeling as such, but basic research on vertical diffusion processes, kinetics of sedimentation processes, air-sea interactions, rate processes of uptake by organisms, and so on. Model building is an interesting and useful occupation and proceeds at a greater rate than fundamental research on the aforementioned subjects. This is fortunate since the model can be used to guide that research, point out shortcuts, arouse suspicion of results, and suggest linkages that would not be apparent without recourse to a model which is capable of thinking in a nonlinear fashion. (Lord Rayleigh and a few other selected individuals are capable of nonlinear intuition. One can only hope that his like will continue to remain a pace ahead of the next generation of computer juggernauts.)

In summary, we seem to have gone through a period of extensive model development; in some degree progress has been in parallel with advances in computer hardware. Computerized model development, involving numerical witchcraft, has rapidly caught up with, and is capable of treating, what we know of biochemical interactions. Further progress will be at a slower rate in the future because basic research is required on all aspects of estuarine problems, including hydrodynamics.

In this day of "mission oriented" research, there is a danger in neglecting non-mission identified programs. This neglect is, of course, pitiful in the extreme when the neglecter is also a federal budgeteer.

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PORTS

FACTORS BEARING ON POLLUTION CONTROL IN U.S. PORTS LOCATED IN ESTUARINE AREAS

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ABSTRACT

Ports must meet environmental demands during a period when they are faced with abrupt changes in terminal design and operations. Attention must be given to increased costs, due to delays and confusions that will affect the economic productivity of our ports. Additional and equal attention must be placed on the effect port development will have on the existing and future ecology of our estuarine areas.

INTRODUCTION

Concern for the port environment is a recent phenomenon—10 years ago, the concern did not exist on a broad basis as it does today. Admittedly, it is still a new field in which the government and industry along with individuals are seeking ways of operating within new legislation and guidelines. Environmental concerns at the level we know them today have grown so suddenly, U.S. ports have found it necessary to make immediate adjustments to cope with them. These concerns include: legislation, federal agencies, dredging-disposal of spoils, federal permits, environmental impact statements, disposal of oily wastewater and ballast water, disposal of sanitary wastes, dilapidated piers-floating debris, land acquisition, oil spills, coastal zone management, deepwater ports, insurance demands, and vessel traffic safety systems.

Ports are also faced with abrupt changes in terminal and vessel design and operations, including increased size of petroleum and hazardous liquid carriers, super cargo ships in the container trade, bulk carriers, lash and feeder ships, tug-barge concepts, speedy hydro-foils, catamarans and surface effect ships, conversion or abandonment of finger piers, reclaiming flat lands for multi-million dollar container facilities, specialized ports, and regional port concepts. The ship operator and customer continue to demand fast turn arounds. All have environmental implications.

FUNCTION AND TRENDS OF U.S. PORTS

If we are to give proper attention to the subject, it is necessary to place in perspective the role U.S. ports play in our economy today, and the projection of "things to come." The value of U.S. port operations and their impact on our economy are shown in

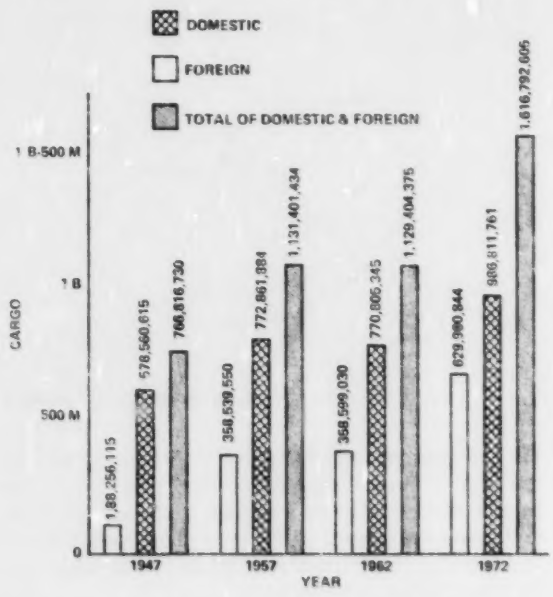

FIGURE 1.—Waterborne commerce in U.S., calendar year 1947–1972 in million of tons (2,000 lbs.).

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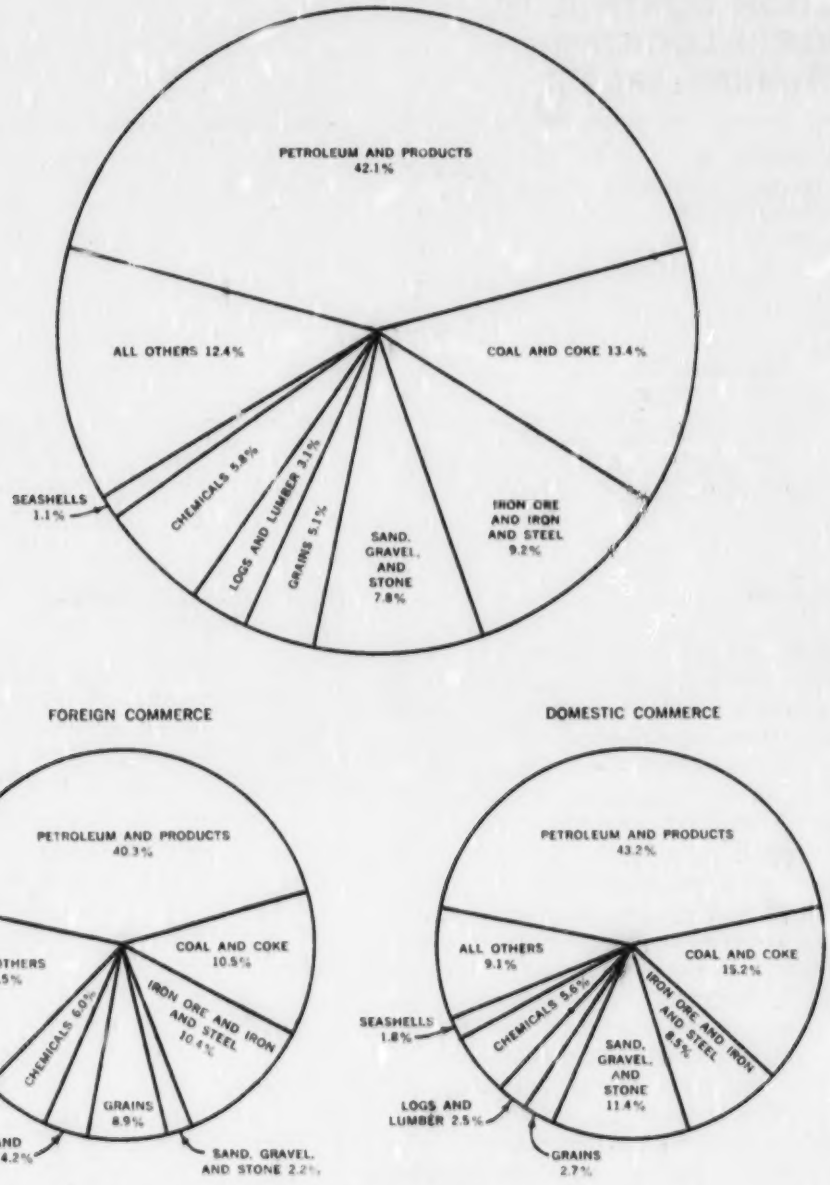


FIGURE 2.—Principal commodities carried by water-calendar year 1972 total commerce.

1972 figures, released by the U.S. Maritime Administration: "Port commerce totals over 1.6 billion tons contributing 30 billion dollars annually in direct dollar income providing livelihood for over 1.2 million people—representing over 3 billion dollars in terminal facility investments."

The growth trend in port commerce since 1947 is shown in Figure 1, and the principal commodities carried by water for calendar year 1972 are shown in Figure 2.

VESSEL TRAFFIC

Two excellent studies were recently completed, projecting future tonnage at United States ports to 2000.[1]

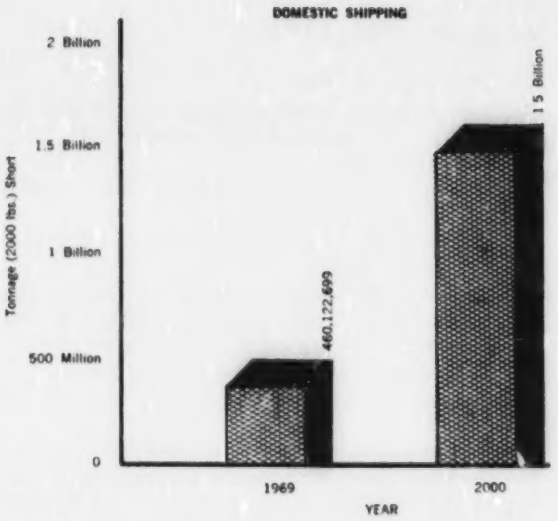


FIGURE 3.—Trends and projection of domestic ocean cargo growth, coastal and intercoastal (including Puerto Rico, Hawaii, and Alaska) 1969–2000, as projected in the Kearney Study.

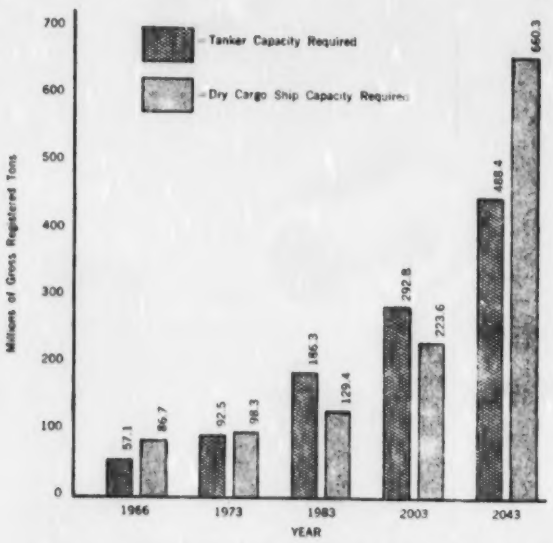


FIGURE 5.—Litton Systems Study showing forecast of growth in the world merchant fleet into 2043.

Figure 3 shows significant trends in domestic ocean cargo (coastal and intercoastal, including Puerto Rico, Hawaii and Alaska), as projected in the Kearney Study.

The Litton Systems Study on the future of oceanborne shipping explores trends in the volume of oceanborne trade, from 1950–1966 with projections to 2043. See Figure 4.

The study also projects trends in growth of the world merchant fleet from 1966 to 2043, which will have an impact on vessel traffic, hence concern for the port environment (Figure 5).

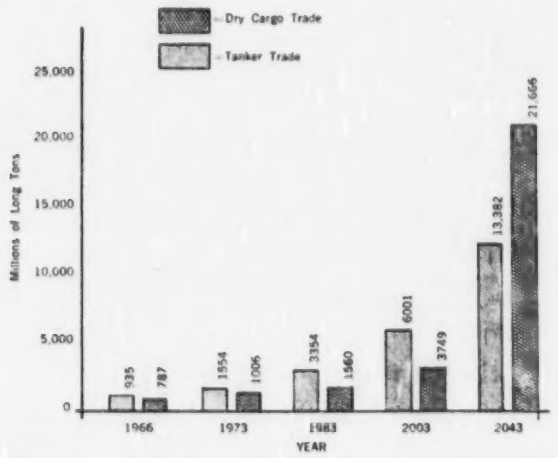


FIGURE 4.—Litton Systems, study of the projection of volume of oceanborne trade into 2043.

The studies show that within the next 15 years development of coastal petroleum tank barge trade will occur as a means of secondary distribution. During the past six years (1968 date of Litton Study), there has been a growing use of tank barges carrying petroleum in the coastal trade. See Figure 6.

The Coast Guard is concerned about the increased movement of petroleum and other liquids in tank barges, towed or pushed along our coastlines. They currently monitor the tank barge service to determine trends and problems.

On July 7, 1972, Congress passed P.L. 92-339, which among other issues, made it mandatory that all operators of tow boats under 300 tons be licensed by the Coast Guard (qualify for Tow Boat Operators License).

Barges carrying liquid product in the coastal trade must be inspected for seaworthiness by the Coast Guard; however, towboats under 300 tons are not required to come under Coast Guard inspection.

REGIONAL PORTS

Discussions are taking place in several port areas throughout the country, focusing on a regional port concept. Those areas include the Washington Public Ports Association, the San Francisco Bay area, and the New York ports of Buffalo, Ogdensburg, Oswego, and Albany.[3] There is some thought that the "re-

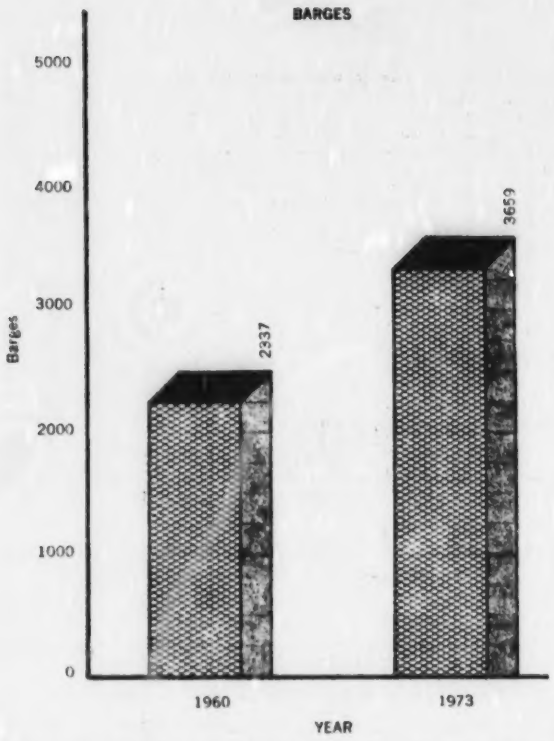


FIGURE 6.—Trend in use of tank barges (towed or pushed) in inland waters and coastal services, under Coast Guard inspection. Note: Inland waters and coastal numbers were not separated until 1973. Percentage increases for individual services will be recorded separately in the future.

gional port concept" is sponsored by the federal government and is an intrusion into the free enterprise system. However, it must be noted that studies at current port areas were initiated at the local level.

One of the principal objectives of the studies is to determine the value of a number of small ports versus a regional port to serve U.S. trade, and keep U.S. products flowing into competitive world markets. A secondary benefit would be cleaner coastal water with all commercial activity centralized at one port, rather than a number of small ports. The major pollution concern would be to mobilize funds, expertise, manpower, and equipment at one port to prevent and control possible oil spills and other pollutants from vessel traffic and port operations.

FEDERAL LEGISLATION

Some of the pertinent federal legislation influencing port environment and operations from 1969 to the present include, by title:

Refuse Act of 1889
Federal Water Pollution Control Act (FWPCA) of 1948. (As amended 152-61-65-66-70-72) P.L. 91-224 (4-3-70)
Federal Water Quality Standards Act of 1971. P.L. 92-500 (10-18-72)
Ports and Waterways Safety Act of 1972. P.L. 92-340 (7-10-72)
Marine, Protection, Research and Sanctuaries Act of 1972. (Ocean Dumping Act) P.L. 92-532 (10-23-72) (As amended 1974, P.L. 93-254)
Deepwater Ports Facilities Act of 1974.
Coastal Zone Management Act P.L. 93-583 (10-27-72)

This legislation, with resulting regulations and federal agency administration, requires constant attention and monitoring by port personnel.

FEDERAL AGENCIES INVOLVED

As new federal legislation was passed, and regulations and directives written, port directors and terminal operators found it difficult to keep informed. Communications between federal agencies and port directors were improved by a series of meetings arranged through the American Association of Port Authorities and the U.S. Maritime Administration.

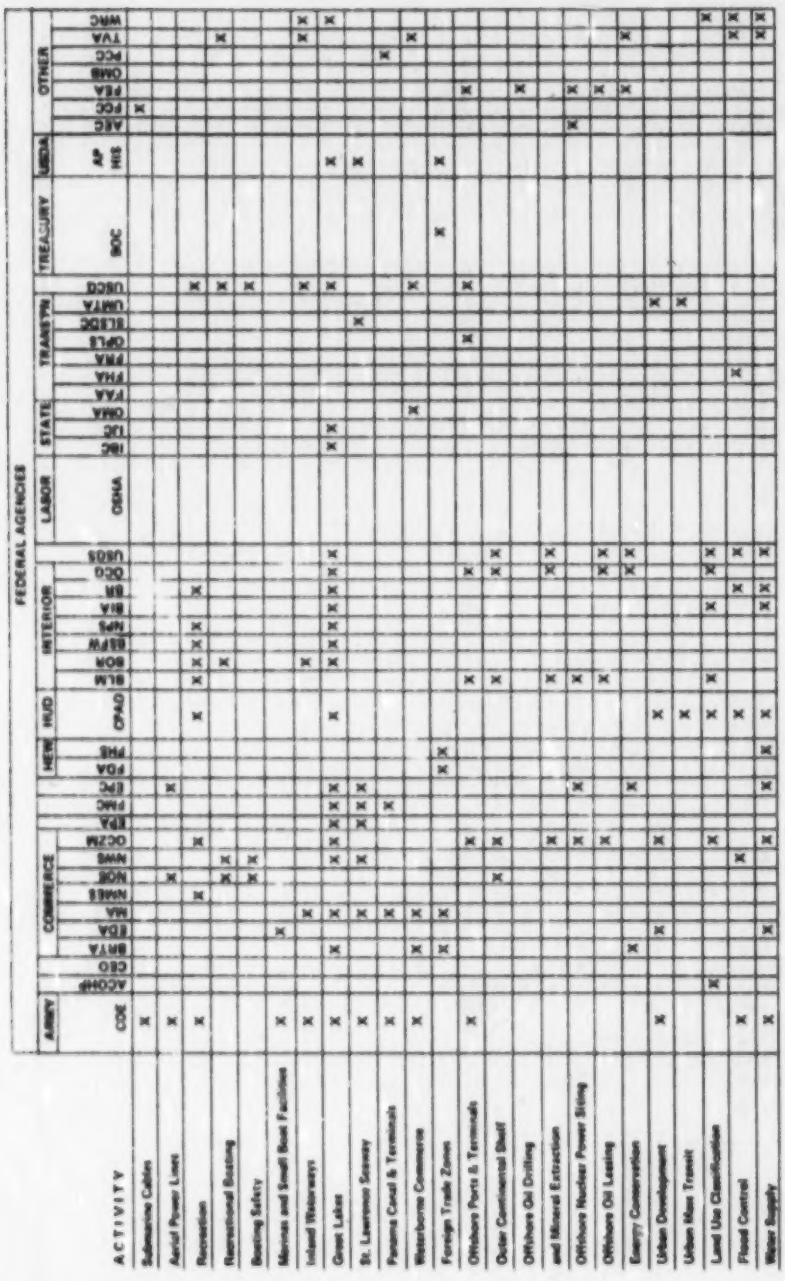
Figure 7 is a matrix listing of federal agencies involved in a port environment, depicting areas of overlap in duties and responsibilities, which tend to cause confusion in the port industry. This situation is particularly reprehensible when the agencies work in consort to prepare adverse reports on a specific project, but then file separate objections as if their determinations were individually and independently reached.

It is difficult to quantify the extent of the confusion, its impact and resulting delays and costs, other than to state that it exists and attention must be given to clarifying the situation. The matrix shows there are 69 separate port environment activities involving over 50 federal agencies or bureaus. It shows over 550 different steps must be taken to process port-related activities.

DREDGING-DISPOSAL OF SPOILS

The Army Corps of Engineers, in fulfilling its mission in the development and maintenance of the navigable waters of the United States is responsible for the dredging of large volumes of sediments each year. Annual quantities approach 400 million cubic yards of dredge material for both maintenance and new work. Costs

| ACTIVITY | FEDERAL AGENCIES | | |


FEDERAL AGENCIES
ARMY
COE
COMMERCE
ACOHHP
CEQ
BMTA
EDA
MA
NMES
NOS
NWS
OCZM
EPA
PMC
EPC
HEW
FDA
PHS
HUD
CPAD
INTERIOR
BLM
BOR
BSFW
NPS
BIA
BR
BCG
USGS
LABOR
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SLSDC
USMTA
USCG
TREASURY
SOC
USDA
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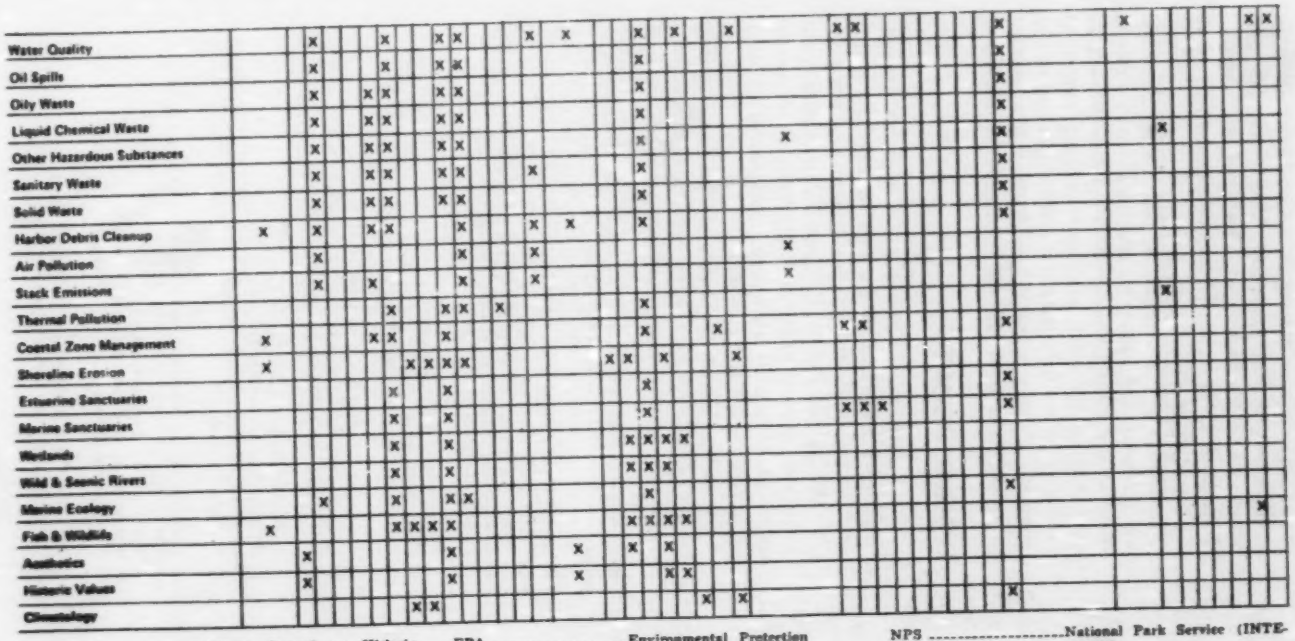
WRC
ACTIVITY
Submarine Cables
Aerial Power Lines
Recreation
Recreational Boating
Boating Safety
Marinas and Small Boat Facilities
Inland Waterways
Great Lakes
St. Lawrence Seaway
Panama Canal & Terminals
Waterborne Commerce
Foreign Trade Zones
Offshore Ports & Terminals
Outer Continental Shelf
Offshore Oil Drilling
and Mineral Extraction
Offshore Nuclear Power Siting
Offshore Oil Leasing
Energy Conservation
Urban Development
Urban Mass Transit
Land Use Classification
Flood Control
Water Supply



ACOHP ..... Advisory Council on Historic Preservation
AEC ..... Atomic Energy Commission
APHIS ..... Animal and Plant Health Inspection Service (USDA)
ARMY ..... Department of the Army
BIA ..... Bureau of Indian Affairs (INTERIOR)
BLM ..... Bureau of Land Management (INTERIOR)
BOC ..... Bureau of Customs (TREASURY)
BOR ..... Bureau of Outdoor Recreation (INTERIOR)
BR ..... Bureau of Reclamation (INTERIOR)
BRTA ..... Bureau of Resources & Trade Assistance (COMMERCE)
BSFW ..... Bureau of Sports, Fisheries & Wildlife (INTERIOR)
CEQ ..... Council on Environmental Quality (EXEC. OFC. OF PRESIDENT)
COE ..... Corps of Engineers (ARMY)
COMMERCE ..... Department of Commerce
CPAD ..... Community Planning & Development (HUD)
EDA ..... Economic Development Administration (COMMERCE)
EPA ..... Environmental Protection Agency
FAA ..... Federal Aviation Administration (DOT)
FCC ..... Federal Communications Commission
FDA ..... Federal Drug Administration (HEW)
FEA ..... Federal Energy Administration
FHWA ..... Federal Highway Administration (DOT)
FMC ..... Federal Maritime Commission
FPC ..... Federal Power Commission
HEW ..... Department of Health, Education & Welfare
HUD ..... Department of Housing & Urban Development
IBC ..... Internation Boundary Commission (US-CAN & US-MEX)
IJC ..... International Joint Commission (US-CAN)
INTERIOR ..... Department of the Interior
LABOR ..... Department of Labor
MA ..... Maritime Administration (COMMERCE)
NMFS ..... National Marine Fisheries Service (NOAA-COMMERCE)
NOS ..... National Ocean Survey (NOAA-COMMERCE)
NPS ..... National Park Service (INTERIOR)
NWS ..... National Weather Service (NOAA-COMMERCE)
OCZM ..... Office of Coastal Zone Management (NOAA-COMMERCE)
OMA ..... Office of Maritime Affairs (STATE)
OMB ..... Office of Management & Budget (EXEC. OFC. OF PRESIDENT)
OCG ..... Office of Oil & Gas (INTERIOR)
OPLS ..... Office of Pipeline Safety (DOT)
OSHA ..... Occupational Safety & Health Administration (LABOR)
PCC ..... Panama Canal Company
PHS ..... Public Health Service (HEW)
SLSDC ..... St. Lawrence Seaway Development Corporation (DOT)
STATE ..... Department of State
TRANSPORTATION ..... Department of Transportation
TREASURY ..... Department of the Treasury (CUSTOMS)
TVA ..... Tennessee Valley Authority
UMTA ..... Urban Mass Transportation Administration (DOT)
USCG ..... U.S. Coast Guard (DOT)
USDA ..... U.S. Department of Agriculture
USGS ..... U.S. Geological Survey (INTERIOR)
WRC ..... Water Resources Council

presently (1974) exceed $150 million per year and can be expected to increase sharply, reflecting at least in part, the cost of attempting to reduce the potential for pollution of the environment.

* * * * *

The Corps presently maintains over 19,000 miles of waterways and 1,000 harbor projects. In the past, the Corps' decisions concerning open-water disposal of dredged materials have been based primarily on economic considerations. Plans for future dredging and disposal activities must now reflect proper considerations of costs and environmental constraints.

* * * * *

Due to the fact that dredging and the disposal of dredge materials occur in such highly variable environmental situations, it has been generally accepted that a universally applicable methodology cannot be satisfactorily developed. Consequently, it was concluded that a broad based program of research was required to provide definitive information on the environmental impact of dredging and dredged material disposal operations.[3]

* * * * *

The overall objective of the Dredged Material Research Program (DMRP) is to provide sufficient decision-making tools to those agencies with dredging and disposal responsibilities to enable them to choose the most environmentally compatible, technically satisfactory, and economically feasible disposal alternatives.[4] See Figure 8.

In 1973, Committee XV (Environmental Affairs) of the American Association of Port Authorities conducted a survey among its members to determine environmental port problems. Thirty-six U.S. corporate members responded. Dredging and disposal of spoils proved to be the major problem of 16 of the reporting ports.

In 1974, AAPA Committee III (Ship Channels and Harbors) conducted a National Seaport Federal Waterway Funding Survey. Of the 54 responses, 24 cited serious disposal problems causing increased costs and delays for channel construction and maintenance. "Spoils disposal problems are evidently affecting many port regions," the report indicated.

FEDERAL PERMITS

The Federal Water Pollution Control Act Amendments of 1972 established a new system of permits for discharge into the nation's waters, replacing the 1899 Refuse Act Permit Program. The federal agencies given responsibility for protecting our oceans and waterways with their permitting authority may be found in the matrix (Figure 7).

The Army Corps of Engineers retains authority to issue permits for the disposal of dredge fill material in specific disposal sites, subject to EPA veto of

RESEARCH AREA	RESEARCH TASK
Environmental Impact and Aspects of Open Water Disposal	A. Evaluation of Disposal Sites (1)* B. Fate of Dredged Materials (1) C. Effects of Dredging and Disposal on Water Quality (1) D. Effects of Dredging and Disposal on Aquatic Organisms (1) E. Pollution Evaluation (1)
Environmental Impacts and Aspects of Land Disposal	A. Environmental Impact Studies (1) B. Marsh Disposal Research (1) C. Containment Area Operation Research (1)
New Disposal Concepts	A. Open Water Disposal Research (2) B. Inland Disposal Research (3) C. Coastal Erosion Control Studies (3)
Productive Uses of Dredged Material	A. Artificial Habitat Creation Research (1) B. Habitat Enhancement Research (2) C. Land Improvement Research (3) D. Products Research (2)
Disposal Areas Reuse and Multiple Utilization	A. Dredged Material Drainage/Quality Improvement Research (2) B. Wildlife Habitat Program Studies (1) C. Disposal Area Reuse Research (1) D. Disposal Area Subsequent Use Research (2) E. Disposal Area Enhancement (2)
Dredged Material Treatment Techniques and Equipment	A. Dredged Material Dewatering and Related Research (2) B. Pollutant Constituent Removal Research (1) C. Turbidity Control Research (1)
Dredging/Disposal Equipment and Techniques	A. Dredge Plant Related Studies (3) B. Accessory Equipment Research (2) C. Dredged Material Transport Concept Research (4)

* Numbers in parenthesis indicate the beginning year of the research task.

FIGURE 8.—Outline of dredged material research program.

disposal sites. However, in the new Corps permitting system, no time schedule for processing permits has been developed. When objections are raised at the district level, an extensive time lapse develops while a decision is considered at a higher level.

There is no indication that the requirement to obtain permits for port projects is opposed by the port industry. However, it is important that there be no long delays in granting permits which might result in added costs to port projects, with possible adverse effect on the water quality in estuarine areas.

ENVIRONMENTAL IMPACT STATEMENTS

The EIS is now a responsibility under the National Environmental Policy Act (NEPA) of 1969—Section 102 (2) (c). The program is administered by the Council on Environmental Quality (CEQ), established under Section 202 of the NEPA.

An EIS must be filed for all projects which significantly affect the quality of the human environment and for which a major federal action, such as funding or licensing, is involved. The EIS must take into consideration the economic values of a project as well as the environmental impact. A healthy balance must be retained for the welfare of the ports and the country.

The Army Corps of Engineers has 900 environmental impact statements to write on maintenance projects alone. At the present rate, the Corps can only handle about 60 EIS a year, although, as of January 1, 1976, every Corps project will require an EIS.[5] Several ports have indicated problems resulting from the requirement to provide an EIS. It is difficult to quantify and document each problem; however, general comments express concern over agency guidelines being changed during preparation of the project and where more than one agency is involved, the conflicting guidelines used by different agencies in judging the project.

DISPOSAL OF OILY WASTE AND BALLAST WATER

Based on the President's message of May 20, 1970, directing the attention of the port industry to the problem of "Facilities for the Reception of Ships' Oily Waste and Ballast Water," the Maritime Administration (Division of Ports and Terminals) and the American Association of Port Authorities established an ad hoc committee to review, study, and propose action. The committee consisted of representatives from the U.S. Maritime Administration, Environmental Protection Agency, American Institute of Merchant Shipping, American Petroleum Institute, U.S. Coast Guard, and the American Association of Port Authorities.

As a result of this Committee's recommendation, a contract was awarded to conduct a study to:[6]

a. Determine the volumes of oil waste which would arrive at U.S. ports under various restrictions or permissible discharge.

b. Define systems for collecting and processing these volumes.

The study identifies the types of oily wastes brought into nine selected ports by commercial shipping and estimates 1970 quantities based on "no discharge" criteria, the "1969 Amendments," and the "no sheen" criteria. Quantities for 1975 and 1980 are also estimated, with the report concluding that 16.5 billion gallons of oily waste would be collected at U.S. ocean and inland ports in 1975, rising to almost 17.0 billion by 1980. If reception facilities are not available, there is no way to determine if, in fact, any of these wastes would reach estuarine areas. Ships today are prohibited from pumping bilge and ballast water in U.S. ports. If, however, the IMCO Convention specifics are not in force by 1980, ships will still be able to pump these wastes at sea.

Conceptual designs for collecting, treating, and disposing of the oily wastes, with no additional environmental degradation, range from the use of oil-water gravity separators in small volume ports, to large storage tanks adjacent to separator and/or refining capabilities in larger ports.

The suggested role of government is limited to assisting business in expanding existing capabilities through grants, loans, and research. When government-owned facilities are available, the study recommends leasing to entrepreneurs.

The problem has not at this time been defined regarding costs versus income to an entrepreneur, a port authority, or private terminal operator who must provide the necessary facilities. These would include:

a. Reception capabilities
b. Storage capabilities
c. Separation and treatment capabilities
d. Obtaining necessary permits to discharge separated water back into surface waters
e. Service charge to ship operator with possible resulting increased cost to consumer
f. Disposing of reclaimed oil, or disposing of waste oil
g. Possible delays to vessel with resulting costs

The role of the entrepreneur is not clearly defined. Refinement of regulations and policies is necessary before any large investments are made by the businessman.

Industry has entered into several programs to alleviate the problem of disposal of oily waste generated aboard ship, without direct discharge into the seas and waterways:

a. Load on top method
b. Holding tanks
c. Improved tank cleaning
d. Oil water separator
e. Segregated ballast tanker

Research by the Coast Guard and the American Institute of Merchant Shipping have not as yet established numbers or costs on these methods or total effectiveness of these programs. At this time it appears that no statistics are available. Very few American flag vessels are capable of the above. Coast Guard is making an effort to learn the impact, effectiveness, and costs of these innovative programs.

The study revealed that only two ports in the country (Burns Waterway Harbor, Ind., and Seattle, Wash.) were capable of receiving and processing bilge and tank cleaning water.

The Maritime Administration is currently involved in a project to accept, treat, and dispose of ship-generated oily waste at their recently acquired Cheatham Annex Complex in York County, Va. To date, no product has moved through the facility so no numbers are available.

The Maritime Administration also awarded a contract to determine the feasibility of "Floatable Oily Waste Treatment Systems." This study determined that it would be too expensive to use old Liberty ship hulls, placed in U.S. harbors for this project. There is also a limited supply of Liberty ships available. No further action is planned.[7]

The Maritime Administration has also commissioned studies to determine the functional capabilities and costs for volume acceptance of oil waste separation units aboard ship. If a unit can be developed to function properly aboard ship, it would help to eliminate the port problem of providing reception facilities. To date it appears no feasible shipboard unit will function properly under all conditions to handle the problem.

Ports must have an oily waste implementation program operational within 12 months after 15 nations have signed the IMCO Agreement, or by January 1, 1977.[8]

DISPOSAL OF SANITARY WASTES

It is increasingly apparent vessels will be prevented from discharging untreated sewage in U.S. territorial waters. EPA has established a "no-discharge" standard for all vessels.

The Coast Guard proposed regulations to implement EPA's standards for marine sanitation devices were published in the Federal Register on March 1, 1974. The proposed regulations govern the design, construction, testing, certification, and manufacture of marine sanitation devices. Public hearings were conducted inviting comments and suggestions. The Coast Guard is presently redrafting the regulations based on the input.[9]

More than half of the comments received were directed in whole or in part to the EPA standard. The gist of these comments was objection to the federal no-discharge requirement. In view of this general discontent with the standards, the Coast Guard has broached with EPA the question of the efficacy and appropriateness of the existing standards. Discussions between the agencies is currently underway.[9]

The Coast Guard and Navy are studying and experimenting extensively with equipment and methods of operation within their own vessels to meet EPA and state requirements and standards.

The Maritime Administration also has an extensive research and development program on the disposal problem of sanitary wastes. Using Liberty ships to accept sanitary wastes from vessels and municipalities was explored but proved too costly and ineffective.[10]

The recreational fleet, which is a significant factor in the water quality of any port must also meet standards and criteria. Marinas to service this type of vessel have introduced pump-out and reception facilities ashore, but no inventory has been taken to date and the impact is not known.

Major commercial ports in the United States have done little to provide for the reception of liquid sanitary wastes from commercial vessels of all types and sizes. The only ports with significant waste reception facilities are Burns Harbor, Ind., Toledo, Ohio; Miami, and Jacksonville, Fla.[11] It would appear that port areas will need guidance as to required hookups to receive sanitary waste at pier facilities and proper lead time to install them.

While attention is being given to the reception of sanitary wastes from vessel operation, it is important to note that port and harbor waters will not improve in quality until such time as all municipal wastes now emptying into the harbors are diverted to municipal treatment plants.

DILAPIDATED PIERS—FLOATING DEBRIS

A problem having great significance on the immediate port environment has been the deterioration of dilapidated port structures resulting, in part, in varying degrees of floating debris. In the past, a cooperative, yet not specifically defined program of federal and local effort functioned to remove dilapidated wharves and to collect and remove drift from navigable waterways.

To add additional confusion to an already misunderstood and fragmented program, involving the U.S. Army Corps of Engineers and the Coast Guard, the Federal Office of Management and Budget (OMB) in early 1973, announced its opposition to any federal subsidy for removal of drift and dilapidated piers. This decision was based on costs and OMB opinion that this is a local port problem.

Dilapidated structures and floating debris involve three major port environmental problems:

a. Visual pollution
b. Floating debris hindering the collection and disposal of spilled oil
c. Large floating logs, a danger to small boats

The Department of Transportation, through the U.S. Coast Guard, sponsored an exhaustive debris study. The types and quantities of waterborne debris found in coastal, harbor, and estuarine areas are described in the report. Regional variations of the types and quantities of debris, its sources, and the natural effects on concentration and quantity are described. Debris handling practices are discussed and equipment is identified and evaluated.[12]

Many recommendations are made including the suggestion that the Coast Guard initiate or become involved in joint debris oriented programs with the Environmental Protection Agency, the Corps of Engineers, and the Navy. It is claimed in the 460-page study that this will help to eliminate overlapping efforts by these organizations.

Inconsistencies in the debris programs find the Army Corps of Engineers financing some port debris pickup programs, while physically participating in others. Among the ports who finance their own debris pickup and patrol programs are Baltimore and Miami.

LAND ACQUISITION

In January 1975 the Environmental Affairs Committee of the American Association of Port Authorities, conducted a survey among its 80 U.S. corporate members to determine if they were experiencing any problems because of environmental legislation in acquiring the necessary land for expansion of existing port facilities. Nine ports reported problems in acquiring land for expansion and nine others reported problems in obtaining land within their existing port facilities. The survey also asked if U.S. ports were experiencing problems in obtaining permits to develop the land. The survey indicated permitting problems existed at the local, state, and federal levels.

The Port of Oakland, Calif. reported as follows:

> With regard to the portion of your questionnaire and survey dealing with land acquisition, we face problems of securing necessary approvals from as many as 31 different agencies in a typical port project. I hope in the coming year, AAPA through its various committees, will develop firm and strong recommendations as to how these problems can be met and what solution should be sought.[13]

COASTAL ZONE MANAGEMENT ACT OF 1972

Response to the above survey indicates that the 35 responding ports are aware of this Act. However, only 23 of the responding ports reported they were involved in the planning and implementation of the Act in their state, and only 23 had assigned personnel to be involved in the planning and implementation. Twenty-nine ports felt port authorities should be involved.

Thirty ports reported they had growth plans requiring expansion involving over 15,000 acres between now and 2000. It was disturbing to note, however, that only 17 ports had brought their growth plans to the attention of the coastal zone management authorities in their state.

A factor that will be of considerable importance to this program and the future of U.S. ports, is the Maritime Administration (MarAd) NOAA Memorandum of Understanding which was consummated November 20, 1973, regarding MarAd assistance in port and navigation facilities development in the coastal zone. In view of the integral role which coastal zone management plays in MarAd programs and activities, MarAd will receive from NOAA individual state and territory coastal zone management programs for review and return a written evaluation and commentary. Under this agreement, MarAd will be in a position to exercise some influential comment on pollution and pollution control at the port level. To date, MarAd has received no coastal zone management plans for review.

OIL SPILLS IN OUR PORTS AND HARBORS

This is an ever-increasing problem and one that requires considerable attention from government and industry at all levels. Oil spills from vessel and terminal operations are mostly unintentional, the cause of a miscue by manpower, or malfunction of equipment. In some instances oil is spilled intentionally by poor judgment through pumping of ballast or bilges. Regardless of the type of incident, oil is deposited in our waterways, costing millions of dollars in cleanup and ecology damages. Research and development projects through EPA, MarAd, Coast Guard, Navy and industry have resulted in improving the still primitive state of the art to attack an oil spill by controlling, removing, and disposing of it. But much remains to be done.

There is a newly formed national trade association representing the interests and serving the needs of the oil spill and hazardous substances control industry. Membership is open to all interested parties; however, members are primarily (1) third party contractors; (2) manufacturers or suppliers of equipment; (3) individuals in private or governmental capacities involved with oil and hazardous substances spill cleanup and containment operations.[14]

Objectives of the new organization are: (1) communication of the industry's practices, trends and achievements; (2) establishing liaison with governmental agencies; (3) developing industry standardizing programs; (4) assisting the industry, wherever appropriate, regarding insurance; and (5) obtaining radio frequency allocations for oil spill operations.

EPA has published regulations involving shoreside facilities, and the Coast Guard has published regulations on shipboard operations, both designed to control oil spillage. So far, both programs are lagging.[15]

EPA estimates there are more than 14,000 oil spills in U.S. harbors and waterways a year. EPA reports nearly 3 million gallons of oil were spilled in 83 cases investigated by EPA in the first quarter of 1974. EPA has introduced a new 2.6 million gallon test tank at Leonardo, N.J., in an effort to find better ways of handling the nation's "intolerable number of oil spills."[16]

ENVIRONMENTAL CONSIDERATIONS FOR DEEP WATER PORTS

The Administration has recognized the need for establishing offshore deepwater port facilities and the need for new comprehensive legislation to govern their establishment and operation.

More than 100 ports in the world are capable of handling the large supertankers, and there are over 300 tankers of 200,000 DWT, or more. This is clear evidence that consideration must be given to facilities to handle this size vessel serving our energy needs. The Port Facilities Act of 1974 was designed to give attention to this subject.

ATTITUDES IN ENVIRONMENTAL AFFAIRS

The American Association of Port Authorities, comprised of over 80 U.S. ports, recognizes the port industry's responsibility to the environment. In 1970, AAPA authorized the formation of Committee XV (Environmental Affairs), with specific duties and responsibilities.

In 1972, AAPA Directors authorized competition among U.S. ports for the "Recognition of Outstanding Environmental Programs" award to encourage additional attention to environmental responsibilities by port authorities. In 1973, 14 U.S. ports entered the competition and in 1974, 11 entered. Extensive briefs were presented to the judges, who represented EPA, Coast Guard and MarAd.

> Programs included improvement and beautification of port property through planting of grass, trees, and shrubs; painting structures; providing barrier screens; installing sewage systems; eliminating open burning; removing deteriorated piers; oil spill contingency plans; port personnel participating in community environmental programs; construction of park with lighted walkways; fountain, picnic tables, etc.; directives to reduce air pollution; encouraging businessmen in the port to improve their environmental habits; program to prevent salt water intrusion into viable estuaries; dust control program; dredging and spoil disposal programs; traffic control systems to prevent accidents; providing equipment to control pickup and dispose of spilt oil in the harbor; debris removal; establishing performance standards; 100 acre public park with bicycle park and trails; recycling program for port generated paper; bond issues to finance pollution control equipment; regulations on noise abatement; and landscape design.

Several ports are now employing personnel with full time assignments on environmental affairs. The California Association of Port Authorities has announced the appointment of a planning and environmental consultant.[17]

INSURANCE DEMANDS ON U.S. PORTS

Indications at this time are that ports are not experiencing any major financial hardships imposed by additional costs for insurance because of environmental constraints. However, a prominent Washington attorney with experience and expertise on

pollution control laws and their impact on the Marine Industry, concluded his paper before a recent conference in Washington with this statement:

> The foregoing pages outline a body of law that is comprehensive, complex and constantly changing. It isn't surprising, therefore, that the traditional response of many marine industry executives has been 'Let the insurance carriers worry about the law. I need to tend to my business'. While this approach may have worked in the past, rapid growth of regulatory requirements affecting the design and operation of vessels and shoreside facilities gives rise to the inescapable conclusion that effectively accommodating to the regulatory environment is a substantial part of the "business" which needs tending to and can, in fact, mean the difference between profit and loss. When pollution abatement requirements can add nearly 25 percent to the cost of a vessel, it is clearly essential to make certain that such requirements do not discriminatorily affect your operations vis-a-vis those of your (domestic or foreign) competitors.[15]

VESSEL TRAFFIC SAFETY SYSTEMS

Coast Guard continues to expand its activities and responsibilities to improve maritime safety in harbors and waterways as it accelerates implementation of the Ports and Waterways Safety Act of 1972. Traffic safety can be the number one deterrent to vessel casualities, thereby reducing the spillage of oil in the waterways. The U.S. Coast Guard seems to have an effective program underway. Systems in San Francisco and Puget Sound are presently in operation and regulations have been drafted to require their mandatory use. Systems for other selected ports are in the planning or construction stage.

Ports and waterways have been ranked according to their need for vessel traffic systems. The list is based on an analysis of casualty statistics utilizing an algorithm developed through the VTS Issue Study. (March 1973.)

The Coast Guard programs on bridge to bridge radio-telephone communications will contribute greatly to traffic safety, and reduction of casualties.

The need for attention to the orderly control of shipping in and out of our waterways is apparent with the increased size, carrying capacity, and volume of traffic existing today and projected for the future. The following chart depicts the growth and size of petroleum carrying vessels from 1956 to present date:

Name	*Tons*	*Bbl. cap.*	*Launched*
Sinclair Petrolore	56,089	350,000	1956
Universe Leader	85,550	550,000	1957
Universe Apollo	104,520	800,000	1959
Manhattan	108,590	900,000	1962
Nissh Maru	130,250	950,000	1962
Tokyo Maru	130,250	950,000	1966
Idemitsu Maru	206,000	1,700,000	1966
Universe Ireland	326,000	2,500,000	1968

The following table prepared by the U.S. Navy shows the crash stop capabilities of tankers under full astern conditions:

17,000 ton vessel	5 minutes	1/5 of a mile
200,000 ton vessel	21 minutes	2.5 miles
400,000 ton vessel	30 minutes	4.5 miles

The stopping ability of the giant ocean carriers can be a serious problem both in open and congested waters.

TRENDS AND RECOMMENDATIONS

Three basic trends are apparent. These are indicative of the approach, attitudes, involvement, frustrations, and concern for the future of U.S. ports and the water quality in our harbors, waterways, and estuarine areas.

a. Federal, state and local legislation, guidelines, regulations, and directives will continue and will have their impact on port operations and water quality.

b. The port industry is making adjustments in policy and administration to participate in environmental programs.

c. Facilities, equipment and personnel required to respond to these environmental constraints will present a financial burden to the port industry.

Basic recommendations:

a. Recommend that immediate responsibility be given to a Special Advisory Board to evaluate and resolve confusion, delays and overlapping responsibilities from federal, state and local legislation, guidelines, regulations, and directives and their resulting environmental impact on ports. It is further recommended that this board include members of the port industry.

b. Recommend that immediate attention be given to determine the financial burdens placed on U.S. ports, through environmental constraints and how this might affect the future of U.S. ports and U.S. markets in world trade.

It is recommended that attention and support be given to H.R. 1084, a bill "To amend the Merchant Marine Act of 1920, to establish a

grant program to enable public ports to comply with certain federal standards, to direct the Secretary of Commerce to undertake a comprehensive study of the present and future needs of public ports in the United States, and for other purposes."

Federal legislation on security measures, safety regulations (OSHA), and environmental constraints is bound to have a serious financial effect on U.S. ports. These issues require careful evaluation as to their effectiveness versus costs.

Review procedures that result in conflicts and communication gaps between local, district, and Washington headquarters of federal agencies involved in these projects.

The cost to purchase and develop new land for relocation of facilities and obtaining permits for dredging and spoils disposal for these projects needs to be reviewed.

RECOMMENDATION: (Federal permits)

1. Reduce number of federal agencies required to judge an environmental project. Immediate and careful attention should be given to the matrix (Figure 7), to determine its accuracy and to make recommendations that result in less confusion with resulting delays.

RECOMMENDATION: (Environmental impact statements)

1. Clarify conflicting guidelines from federal agencies for content of material for acceptance of environmental impact statements. Particular attention should be focused on requirements of Department of Interior (Fish and Wildlife) versus Department of the Army (Corps of Engineers).

2. There also appears to be an unnecessary duplication of effort in preparing an EIS. An applicant must prepare an EIS on a project, and the federal agencies with responsibility to this project must also prepare an EIS on the same project. This results in serious time delays.

3. Investigate background of projects requiring an EIS from the Corps. They are behind schedule. Recommend more manpower.

RECOMMENDATION: (Oily waste and ballast water—sanitary)

1. Entire problem needs review and refinement. Coast Guard, EPA, MarAd and AAPA must try to resolve this. Legislation calls for definite action by 1980. The industry does not appear prepared to meet that deadline. Further research and development on shipboard equipment to process the wastes are necessary.

2. The Water Resources Congress has made a recommendation worthy of consideration: "We strongly favor federal regulation and authority to pre-empt state regulations insofar as discharges from vessels in navigable waters are concerned. We also urge development of standards and standard procedures for the removal of shipboard wastes to shoreside facilities."

TRENDS: (Shipping and port industry) The following trends are apparent and require attention:

Increase in cargo movements—increased volume of ship movements—increased size of vessels—new terminal design—port to port service—requirement for new land for port development—deepwater ports—reduction in use of traditional port facilities—changes in handling bulk, liquid and general cargo (large container ships)—overcrowded waterways—increased costs for dredging and disposal of spoils—regional ports—the increased use of LNG vessels—and demand for fast turn-around of ships.

RECOMMENDATION: (Shipping and ports)

1. An overview is needed to establish basic policy changes in funding dredging projects at existing ports versus deepwater ports. The future of traditional ports versus regional ports must be examined. The effect of a large number of smaller vessels versus the supership in relation to vessel safety and avoidance of accidents requires attention.

2. Additional attention is required on the carriage of LNG and the location of port facilities to receive this cargo. Safety precautions must be examined, and further attention is required on how a port and a port community must respond to a major collision of an LNG ship with a tanker or general cargo ship in a restricted ship channel or while tied up at berth.

3. Concern should be continued on the inspection of equipment and licensing of personnel in the carriage

of petroleum products in tank barges (of all sizes) engaged in traffic along the coast.

RECOMMENDATION: (Dredging and spoil disposal)

1. Review criteria published by EPA on constraints to dispose of spoils for a more realistic approach.

2. Attention should be given to assure adequate congressional funding of the Corps dredging responsibilities. The amount of money funded by FY 1976 will not meet the needs for new project and maintenance work.

3. Determine cost to government and ports caused by delays, confusion, and misunderstanding due to conflicting guidelines and demands of state and local environmental agencies versus federal agencies.

RECOMMENDATION: (Dilapidated piers—floating debris)

1. Careful review of present study being conducted by the Corps. Particular attention is necessary to damage, with resulting costs, to bridges washed out during storms from floating debris.

RECOMMENDATION: (Land acquisition—Coastal Zone Management Act)

1. Individual ports should review their states' Coastal Zone Planning Program under the Coastal Zone Management Act to determine how it might affect land acquisition for port development.

2. Attention is also required as to why no Coastal Zone Planning Program has been presented to MarAd under the 1973 memorandum agreement between MarAd and NOAA.

3. Ports should become acquainted with the Coastal States Organization, which was formed in 1969 to provide a vehicle for the interested states to make their views known on marine and coastal programs and policies.[19]

RECOMMENDATION: (Oil spills)

1. More R & D on prevention, cleanup equipment and expertise to respond to a spill. Provide adequate depths in channels and waterways traveled by oil barges serving port areas to prevent groundings with resulting oil spills. Improved and expanded training program for Coast Guard officer assuming on scene command at oil spills. Suggest specialized designated officer classification.

2. Expansion of Coast Guard and private "oil spill" training schools. Examine current program at Texas A & M. Enlarge through government financing if necessary.

3. More attention is needed at the federal level through the office of EPA (and possibly Coast Guard) in providing local communities with criteria, guidelines, and assistance in locating disposal sites for both liquid and solid wastes collected from oil spills. This is a very critical issue, and attention to this problem is essential.

RECOMMENDATION: (Deepwater ports)

1. Before implementation of guidelines and policies, clarification is needed regarding jurisdiction, including issuing of licenses, permits, policing, regulations, construction, underwater lands, safety, pipelines, oil spill control and removal, and so forth.

2. Additional study is required on the effectiveness of a single point mooring in open deepwater ports.

3. If the deepwater (offshore) port issue is broadened beyond the reception of petroleum products, such as the reception and transfer of dry bulk cargos, considerable additional attention is required, particularly as it relates to existing land oriented port areas.

RECOMMENDATION: (Insurance demands)

1. An evaluation of this issue requires additional attention. Ports do not seem immediately affected at this time, but it is apparent that vessel insurance in handling petroleum products will have some effect on product cost.

RECOMMENDATION: (Vessel traffic control)

1. The Coast Guard has an excellent program. Funds should be continued so as not to impair its operation.
2. Avoidance of accidents is the basic deterrent to oil spills.

CONCLUSION

There are many unsolved problems that need attention. The federal government is concerned; the

port industry is concerned. Both hope to solve the problems that still exist in order to improve the environmental health and welfare of our ports and estuarine areas.

REFERENCES

1. An analysis of the markets for domestic waterborne shipping by A. T. Kearney, Inc., of Chicago for MarAd. (Published Feb. 1974 at cost of $600,000.)

   Oceanborne Shipping: Demand and Technology Forecast. (Litton Systems for U.S. Dept. of Commerce. June, 1948)

2. The U.S. Maritime Administration has endorsed the intention to establish Regional Ports through the office of Marvin Pitkin.

3. Excerpts from paper given before 1974 Pollution Control in the Marine Industries, sponsored by the International Assoc. for Pollution Control in Washington, D.C., of May 14, 15 and 16 by A. J. Green, Jr., Research Sanitary Engineer, Office for Environmental Studies, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.; and F. H. Griffis, Major, U.S. Army Corps of Engineers. Program Manager, Dredged Material Research Program, U.S. Army Engineers Waterways Experiment Station, CE, Vicksburg, Miss.

4. Section 123 (i) of Public Law 61-911 directs the Army Corps of Engineers (with EPA assistance) to undertake "A Comprehensive Program of Research, Study and Experimentation Relating to Dredge Spoil," which "shall include but not be limited to, investigations on the characteristics of dredged spoil and alternative methods of its disposal." The Corps has begun the $30,000,000 5-year study under the direction of the chairman of the eight-man advisory committee, BG, Allen Clark, Jr., USA (ret.).

5. Statement of Major General John Morris, of the Army Corps of Engineers at a convention of the Gulf Intracoastal Canal Association in February 1974.

6. Disposal of Oily Waste and Ballast Water from Vessel Operation Study contract was awarded to Frederic R. Harris Inc., in the amount of $654,000.

7. "Floatable Oily Waste Treatment Systems" Study was awarded to Lockheed Shipbuilding and Construction Company; contract amount: $399,040.

8. Statement of Ernest Bauer, chief, Division of Ports and Terminals, MarAd, at the American Association of Port Authorities Convention at San Juan, Puerto Rico, October 1974.

9. From a report dated July 2, 1974 from the desk of J. H. Costich, Comdr. U.S. Coast Guard, chief, Environmental Coordination Branch, by direction of the Commandant to Committee XV of the American Association of Port Authorities.

10. Conducted by Lockheed Shipbuilding and Construction Co. of Seattle, Wash. entitled, "The Feasibility of Using Surplus Ship Hulls for Floatable Harbor and River Waste Treatment Systems" (Published in 1973).

11. According to a survey made by Marine Engineering Log of 70 major U.S. ports and published in the June 7, 1973 issue.

12. Department of Transportation Study conducted by the Battelle Columbus Laboratories. Published March 1974, entitled "Waterborne Debris in Marine Pollution Incidents."

13. Ben E. Nutter, executive director, Port of Oakland, Oakland, Calif. (February 6, 1975).

14. Oil Spill Control Assoc. of America, 20245 West Twelve Mile Road, Suite 205, Southfield, Mich. General Counsel, Marc K. Shaye.

15. EPA published regulations involving shoreside facilities; Coast Guard published regulations on shipboard operations—designed to control oil spillage. (Both programs are lagging, according to statements of both EPA and Coast Guard).

16. EPA introduced a new 2.6 million gallon test tank at Leonardo, N.J.—better ways of handling—(Comments of John R. Quayles, Jr., deputy administrator of EPA, Oct. 2, 1974 at Leonardo, N.J.).

17. Appointment of James L. Lammie, former district engineer at San Francisco.

18. Statement of J. Gordon Arbuckle, attorney with Patton, Boggs & Blow, Washington, D.C., before the Pollution Control in the Marine Industries Conference, sponsored by the International Assoc. for Pollution Control, Washington, D.C., May 14, 15, 16, 1974.

19. Coastal States Organization was formed under the auspices of the National Governors' Conference. Chairman: A. R. Schwartz, Texas Coastal and Marine Council, Austin, Tex.

FACTORS BEARING ON POLLUTION CONTROL IN WEST COAST ESTUARINE PORTS

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ABSTRACT

The value of west coast estuarine ports is established; port operational problems attributable to pollution control are defined and analyzed. Major problem areas, including regulations and procedures, are explained with examples. It is concluded that water pollution control regulations cause the most problems and that they are characterized by unjustifiable delay, risk, uncertainty, and confusion. Remedial recommendations are given.

INTRODUCTION

West coast ports are major transportation interfaces in a worldwide commodity flow system. Whether publicly or privately owned, single or multipurpose, these ports contribute significantly to the nation as well as the regions in which they are located in terms of the availability of goods, balance of trade, and regional employment and development. In 1973, west coast ports handled 95 million tons of cargo valued in excess of $17 billion.[1] Figures on community impact of a west coast port are included in Exhibit 1 of Appendix 1.

West coast ports have generally done an exemplary job in keeping abreast of the demands of shippers and consumers. Recent changes in cargo handling concepts (containers, lighter aboard ship, roll on-roll off) have necessitated many waterfront improvements as well as the development of new facilities and the purchase of new equipment. Most World War II ships have been phased out and the new generation of ships requires wider and deeper channels, berths, and maneuvering areas. According to a Maritime Administration survey,[2] west coast ports invested over $308 million in new and renovated facilities during the period 1966 to 1972; federal investments to facilitate port operations have been many times this amount. Many ports have entered into long-term lease arrangements to amortize the heavy indebtedness incurred by the need to modernize.

Other transportation sectors have also undertaken rapid modernization of their port-related facilities to accommodate efficient and economical intermodal transportation of ocean-going cargo. Many ports now have large container freight stations where goods arriving by truck are consolidated into containers and vice-versa. New port rail yards have been developed which handle a variety of cargos, including, for example, containers on truck trailers, for distribution throughout the U.S.

Since the passage of the various clean air and water acts and the National Environmental Policy Act, west coast ports, especially those located in estuarine environments, have had to face many new problems. The regulations and regulatory procedures associated with these laws have added serious technical and financial burdens, often allowing some ports a competitive advantage over others. Frequently, the real benefits of pollution control programs, as developed by the regulatory authorities pursuant to legislative mandate, are in question; problems ensue over the use of funds on pollution control programs without adequate justification.

Embarking on any pollution control program requires time, justification, technical capability, money, effort, and specific direction. Whenever a major expenditure is required to achieve pollution control requirements, it impacts all social and economic sectors dependent on the port activity. Decisions to develop or improve related facilities may be postponed, new equipment orders are often cancelled, and lease negotiations may be tabled. In the case of west coast ports, the major problem areas appear to involve water pollution control programs, primarily due to a lack of funds, technical capability, or definitive requirements. While some air and noise quality control problems have been reported, these are apparently isolated and relatively minor compared to water pollution control problems.

Federal water pollution control programs which are creating difficulties for west coast ports include

those mandated by the Federal Water Pollution Control Act Amendments of 1972 and the Ocean Dumping Act. Additional authority given to regulatory agencies by the Fish and Wildlife Act of 1958 (and the subsequent Army/Interior Memorandum of 1967) and the National Environmental Policy Act are responsible for related problems.

The implementation and administration of these Acts have significantly contributed to pollution control problems facing west coast ports. The first major pollution control program which affected west coast ports involved dredging. Experience with the regulation of this program can be characterized by the following features:

A. Uncertainty—over whether or not dredging will be permitted, future requirements, and regulatory agency activities.

B. Delays—time required to deal with and coordinate actions of all regulatory agencies involved.

C. Multiplicity of agencies involved—many single purpose agencies, often each with authority over permitting dredging and frequently called upon to review a project more than once, must approve dredging projects.

It is of serious concern to west coast ports that the above features may also affect other programs discussed under the following major problem areas.

MAJOR PROBLEM AREAS

Pollution control problems for west coast ports can be categorized in three main areas: ship operations, port operations, and port maintenance and improvement.

A. Ship operations
   1. Sewage discharge from ships while in port.
   2. Ballast or oily waste discharge from ships while in port.
   3. Accidental oil or other spills from vessels while in port.

B. Port operations
   1. Waste treatment plants
   2. Area runoff

C. Port maintenance and development. (This area involves both the improvement and replacement of landside facilities and the new and maintenance dredging of navigation channels and berths.)
   1. Status of applicable regulations and procedures.
   2. Multiple agency involvement and delays associated with permit processing.
   3. Technical feasibility of, justification for, and costs associated with applicable pollution control programs.
   4. Testing and monitoring requirements.

EVALUATION AND DISCUSSION OF FACTORS

A. Ship Operations

1. Discharge of sewage from ships in port directly into the surrounding waters is prohibited by a number of agencies. Most ship sanitary facilities are fitted to discharge directly overboard; very few have holding tanks, treatment plants, or collecting manifolds that would allow sanitary wastes to be pumped to shoreside treatment plants while in port. One solution is to disallow the use of shipboard facilities and use only shoreside toilets; another is to use portable self-contained units placed on board while a ship is in port. Neither solution is fully acceptable to either ship operators or ports since they both involve extra expense and inconvenience. Impact on shipping not otherwise normally susceptible to U.S. regulations (e.g. foreign operators) must be considered in determining the degree and acceptability of such requirements. Adverse effects on ocean shipping services—en toto largely provided by other than U.S. carriers—must be viewed in terms of world trade, balance-of-payments, and competitiveness.

Many local pollution control agencies, such as California's Regional Water Quality Control Boards, in order to comply with Environmental Protection Agency requirements, adopted blanket policies of prohibiting discharges from ships[2] apparently without adequately investigating available alternatives, the magnitude of the ship discharge problem, or the costs involved. Further, in several areas, ports are required to police such prohibitions and can be held responsible for deliberate or accidental discharges. In implementing this policy, the California board has a commitment to install dockside sewers before approving any application to the Corps of Engineers for a permit involving the construction or maintenance of a wharf or pier facility.

2. Ballast and oily wastes must frequently be discharged from ships before taking on new cargo and for trimming purposes. Such discharges, like the discharge of sewage, are prohibited in port. Some ships clean at sea while others make special trips to cleaning facilities. With regard to trim ballast, vessels must often depart from port in unstable condition until they are far enough at sea to discharge excess ballast or wastes.

Most municipal sewage treatment systems can-

not handle the materials and volumes involved even if their lines are connected to port areas. The only generally available landside solution is to pump ballast and oily wastes into tank trucks or rail cars for transport to special treatment or refining facilities. This solution is very expensive, time consuming, and infrequently available.

3. Accidental spills of oil or other deleterious substances into port waters are always a possibility. The U.S. Coast Guard has developed stringent regulations covering the transfer of such materials; these have significantly reduced the probability of spills. The only reasonably reliable, available method of preventing spills from causing damage in port appears to be through the use of floating curtains to control and facilitate spill cleanup. These curtains are deployed around the vessel on docking and float above and below the water level while transfer operations occur. The question has arisen in many ports over who should purchase and operate these curtains.

B. Port Operations

1. Ship wastes, if pumped ashore, must be treated before they are returned to port waters. In most cases, pipelines, pumping stations and pre-treatment facilities would have to be installed to convey the wastes to municipal plants if they could accept them. Many municipal sewage treatment districts in which ports are located cannot accept the volumes and types of wastes which ships must discharge.

The most likely solution will probably involve construction of dual pipeline collection systems from each berth to separate sanitary and industrial treatment plants. Final distribution could be either through existing municipal systems, if they can accept the wastes, or through new pipeline outfall networks.

2. Storm water overland runoff is believed to be a major contributor to water pollution.[4] Port areas generate large amounts of direct runoff due to the magnitude of their land coverage. Port runoff problems are aggravated by their proximity to navigable waters and the fact that they are necessarily low lying areas often subject to overflow from upland tributary runoff.

Surface runoff from ports may traverse areas of many port-related activities including railyards and truck depots, scrap salvage operations, open storage, and ship repair facilities. Pollution control agencies are increasingly alert to controlling non-point source discharges. If it becomes necessary to treat port area runoff, all storm sewers as well as surface runoff will have to be intercepted and conveyed to a treatment plant prior to discharge in port waters. Understandably, many west coast port officials are concerned over the costs involved with constructing and operating such a system.

C. Port Maintenance and Development

Ports, like other industries, must modernize and take advantage of new technology and changing trends to provide efficient service and to remain competitive. The waterfront environment is unusually harsh and port maintenance must be performed on a continuing basis. Unlike most industries, however, the costs associated with port modernization and maintenance are very high compared to either port facility investment or return.

Investments from which accrued benefits are of a common, long range and often intangible nature and which promote general prosperity but are beyond the capability of private enterprise are frequently undertaken by the government. In the case of ports, such benefits, in the form of marine commerce and international trade, are recognized, and the government invests large sums in port modernization and maintenance. This is common for ports worldwide.[5] Since many pollution control measures would fall into the above category, it would appear reasonable to assume that the government should participate in underwriting expenditures associated with port pollution control.

Having the government as a partner is absolutely essential to west coast estuarine port maintenance and development; however, the partnership has many disadvantages. Federal funding programs to deepen and widen navigation channels, for instance, take an average of 17 years to accomplish. During such long time spans, technology, pollution control programs, and regulations change, and consequently the costs and usefulness of such projects.

The following specific problem areas indicate factors limiting and controlling west coast port development and maintenance from the standpoint of pollution control:

1. The status and applicability of pollution control regulations is often confusing. Most industrial point source discharges have been covered by standards issued by the Environmental Protection Agency under the Water Pollution Control Act Amendments of 1972, P.L. 92–500. Compliance with the National Pollution Discharges Elimination System (NPDES) permit program of P.L. 92–500, while expensive, has at least clarified many point source issues and focused attention on others. Ports are the terminus for many pipelines of which the origins and contents are

often unknown; yet, under the NPDES program, ports are required to apply for and procure permits or curtail discharges from all but storm drain pipelines.

Pollution control regulations, while often promulgated and enforced by federal agencies, are frequently interpreted and enforced in more stringent forms by state and local agencies. In the case of dredged material disposal regulations, the overlapping jurisdictions of both regulatory agencies and federal laws combined with failure of EPA to develop guidelines required by Section 403 (c) has caused great confusion. This situation was described by a member of the California State Water Resources Control Board as "A deplorable lack of coordination between agencies which often results in long delays which are unfair to applicants (for dredging permits) and work a hardship on the agencies involved."[6]

The greatest concern expressed by west coast ports regarding pollution control involves dredging. The status of dredging-related regulations is especially confusing since they are mandated by both the Ocean Dumping Act, P.L. 92–532, and by P.L. 92–500. Dredge disposal criteria for ocean disposal have been promulgated pursuant to P.L. 92–532, but not for inland water disposal as required by P.L. 92–500. This situation has left estuarine ports without any clear-cut regulations. In response to this dilemma, Region IX EPA issued its interpretation of the P.L. 92–532 ocean disposal criteria, modified to meet local requirements, and, as an interim measure, has extended these criteria (with some additional modifications) to cover inland water disposal. To further complicate the situation, only one of the seven California State Regional Water Quality Control Boards adopted these criteria, with modifications of their own; the other six boards reportedly use various criteria. This situation frequently results in more stringent requirements for some ports and consequently in higher dredging costs for those ports. Region IX EPA stated that final dredging criteria would be issued over a year ago. Many projects and agencies have awaited these criteria, promised on a monthly basis; a draft was released in late October 1974.

2. Prior to undertaking port development or maintenance projects, ports must procure permits from many regulatory agencies, most of which administer pollution control programs. Primarily because many pollution control regulations appear relatively nebulous and because most pollution control agencies are under-staffed to efficiently handle permits, obtaining permits is usually arduous.

Again, dredging causes the majority of problems. Both for maintenance and development purposes, dredging permits are sought more frequently by more ports than any other permit. All too frequently, a port spends months going through this process to get permits to accomplish annual maintenance dredging; often contracts must be held up or delayed because the status of or an impending decision regarding a permit is unknown. Many development projects have been deferred or cancelled during the permitting process because of uncertainties, delays, and escalating costs. A participant in a recent dredging conference described the situation: "It seems like we are on a merry-go-round—improper guidelines, rigidly applied, result in virtually impossible project requirements."[7]

3. The technical feasibility of complying with many pollution control regulations, their justification in terms of environmental benefits, and the costs of compliance in economic and social terms are very important issues to west coast ports. The most serious of these issues surrounds dredging, which provides the "lifelines" of ship navigation channels to ports.

There have been many commentaries on the adequacy, impact, and effectiveness of pollution control regulations involving dredging. With respect to the basis for the regulations, a board of consultants to the U.S. Army Corps of Engineers stated that "A correctional campaign based on inadequate evidence may be self defeating."[8] There are many arguments which indicate this may characterize the pollution control program for dredging.

First, the impact of dredging activity on water quality relative to natural resuspension of sediments appears to be small. For example, Dr. Ray Krone, a sediment expert from the University of California, has shown that in San Francisco Bay, the amount of material resuspended into the water column by estuarine wind and waves is many times greater than that due to dredging.[9] With regard to toxic metals, on which major pollution control efforts are expended, it is believed that the major cause of their presence in the water column is urban runoff.[10] Given the urban and industrial activity common to estuaries along the west coast, it is highly probable that the impact of dredging on water quality is relatively very minor. As an overview on this matter, Dr. Krone observes that "The ... (EPA) ... appears to feel compelled to establish guidelines for dredged spoil disposal even in the absence of information showing that publishing such guidelines will lead to improvement of water quality. In view of the large sums of money that observation of the proposed guidelines will require, and that otherwise could be spent in preventing the admission of waste discharges into the waters to prevent accumulation of toxic materials on all sediments, such guidelines should be prepared with sound knowledge of the effects of disposal on

the estuary or stream. As the proposed guidelines show repeatedly, even cursory knowledge is lacking."[11]

Second, no studies have conclusively shown significant deleterious impacts on water quality caused by routine maintenance or well planned new dredging. Dredging, which approximates natural resuspension of sediments, does not add materials to the water column. While no significant changes have occurred in dredging practices in San Francisco Bay in the last 50 years (except that the amounts have increased), the local Water Quality Control Board reports that bay water quality is improving.

Third, the costs associated with compliance with dredging related pollution control regulations are high. In the San Francisco Bay, for example, the normal practice for dredging within the central bay is to dispose of the material at a deep aquatic site just off Alcatraz Island; the regulations prescribe disposal for "polluted" material at some 30 miles offshore in the ocean or on land. The cost for disposing in the prescribed ocean site is approximately three times that of disposing at the Alcatraz site. Without adequate justification, ports are very reluctant to commit such large additional expenditures. An estimate of additional costs due to dredging regulations as applied in San Francisco Bay has been developed and is included in Appendix I, as Exhibit 2.

Since ports are often bound by lease agreements, additional expenses for disposing of dredged materials are usually unbudgeted or unknown amounts which must come from other accounts if available at all. In one instance, funds which had been made available for public fishing piers and parks had to be used instead to cover the added costs of compliance. While the recreational benefits of the public fishing facilities are known, no one can identify significant benefits of complying with the dredging regulations.

Another factor aggravating the added cost situation is that many single purpose agencies with pollution control authority can and do exercise a de facto veto power over the conduct of dredging projects. A recent statement by a representative of the U.S. Bureau of Sports Fisheries and Wildlife illustrates the limited perspective that results in controls on ports; with regard to the necessity and merits of port dredging projects, the representative stated that "Although the proposed EPA criteria state that the selection of disposal sites will be based on considerations of the need for disposal, economic costs involved, available alternatives, and the extent of environmental impact, the Bureau will continue to evaluate dredging projects only from the standpoint of the impact on fish and wildlife resources. Decisions of the Bureau will not be swayed by economic considerations."[12] The Bureau has pointed out that it is their obligation to review dredging projects and to try and serve as advocates for sound biological planning.

It is not apparent that pollution control regulatory agencies are able to adequately identify any significant deleterious impacts which begin to compare with the lost benefits of foregone dredging projects or the added costs associated with compliance with the regulations. The agencies have been queried regarding the impacts of the regulations on numerous occasions with unsatisfactory results. To one query from a Congressman, for example, who asked the EPA "What specific beneficial effects will be achieved as a result of implementing the (dredging) guidelines?" EPA responded: "We believe the (guidelines) will provide a better tool to evaluate dredged spoil disposal in San Francisco Bay waters than was formerly available through the use of national (EPA) guidelines. Accordingly, the resulting evaluations should adequately protect the environment while avoiding the imposition of unreasonable burdens on navigation interests."[13] With regard to this particular response there is significant disagreement over whether or not the regulations have been shown to adequately protect the environment and whether or not they impose unreasonable burdens on navigation interests.

4. Testing and monitoring programs are required as conditions of dredging permits issued by government regulatory agencies. The costs of these programs is high, averaging from approximately 7 percent to 20 percent of the cost of the dredging. Much data has been produced from these mandatory programs but its usefulness in protecting the environment is highly questionable. Three questions regarding program usefulness have never been satisfactorily answered: (a) what is the relationship between constituents tested and water quality: (b) what is the relationship between the limits placed on the constituents (which define whether or not dredging is allowed) and water quality: (c) do the prescribed methods of analysis yield results which are indicative of actual deleterious impacts on water quality?

After reviewing the pollution control regulations and testing and monitoring procedures which are prescribed for dredging, Dr. Ray Krone observed that "The levels (limits) of constituents are arbitrarily set without justification or support of any kind. The real difficulty, from the standpoint of their use for management of dredged spoil disposal, however, arises because of the analytical (testing) methods required. . . . The methods of analysis described appear to determine gross constituents or indexes of

possible pollutants, rather than actual deleterious materials released to the environment."[14]

APPARENT NEEDS

The factors discussed above limit and control west coast estuarine port operation, often to a serious extent. Ports can and do play a vital role in pollution control efforts. The following points express needed reforms in the pollution control efforts as applied to west coast ports:

1. Pollution control regulations and testing procedures must be adequately based and justifiable with regard to results. Their entire impact, including that on the environment as well as on the economy and ports in particular must be evaluated prior to implementation. Also, before any regulations are implemented, agencies administering them should be fully aware of costs and of feasible alternatives available to meet regulation requirements. To this end, agencies proposing regulations or testing procedures should be required to develop both environmental and economic impact statements and to hold public hearings prior to promulgation of the regulations. This view has been endorsed by both the board of directors and the general membership of the California Marine Affairs and Navigation Conference.[15] Sound, complete, reasonable, and workable pollution control regulations can only be developed after social, economic, and environmental impacts and priorities are established, evaluated, and their relationships thoroughly understood.

2. Pollution control regulations must be applied uniformly; specific directions for their use must be supplied to all agencies at federal, state, and local levels which might use them.

3. Pollution control regulatory agencies must be adequately funded and staffed to develop fair, efficient and economical permit and review procedures for the administration of pollution control programs.

4. When pollution control measures are judged to be in the general interest, funds should be made available by the government to implement such measures. West coast ports, already financially burdened through many recent modernization efforts, provide many major contributions to the general interest. Some funding is apparently authorized in the amount of $15 million to remove in-place toxicants from navigable waterways according to Section 115 of P.L. 92–500; to date, however, west coast EPA representatives do not know how these funds can be made available.

CONCLUSIONS

In order for west coast estuarine ports to participate as fully as possible in pollution control programs, uncertainty, delays, and confusion now associated with such programs must be minimized. The perplexing problems which characterize the pollution control program for dredging hopefully can be reduced or eliminated from future programs involving other fields of port activity. A mechanism for the sharing of costs associated with port pollution control programs should be developed and implemented. In addition, a streamlined decisionmaking process for the issuance of port maintenance and development permits should be instituted, allowing full and rapid consideration of the value of port activity.

APPENDIX I

(Referenced to Text Superscripts)

1. From U.S. Department of Commerce figures compiled by the Maritime Administration.
2. U.S. Department of Commerce, Maritime Administration, North American Port Development Expenditure Survey, March 1974.
3. California Regional Water Quality Control Board, San Francisco Bay Region, Interim Water Quality Management Plan, April 1971.
4. San Francisco Bay Regional Water Quality Control Board, Memorandum from Executive Director on proposed shellfish policy, August 1974.
5. U.S. Army Corps of Engineers, Institute for Water Resources, Foreign Deep Water Port Developments, December 1971.
6. California Marine Affairs and Navigation Conference, Summary Proceedings: Ecology, Economics and Dredging—A Balancing Point for Navigation, October 1973.
7. Same as #6.
8. U.S. Army Corps of Engineers, Waterways Experiment Station, Disposal of Dredged Spoil (Technical Report H-72-8) November 1972.
9. Dr. Ray B. Krone, Paper to San Francisco Bay Regional Water Quality Control Board, March 20, 1974.
10. Same as #4.
11. Dr. Ray B. Krone, Paper Evaluating EPA Draft Dredge Disposal Criteria, November 8, 1972.
12. Same as #6.
13. Letter from Paul DeFalco, Jr., Regional Administrator, EPA Region IX, to Congressman Robert L. Leggett, November 30, 1973.
14. Same as #9.
15. Resolution adopted by the California Marine Affairs and Navigation Conference, October 1973.

Exhibit 1

Economic Impact of Port of Seattle*

	Number of Jobs	Gross Annual Payroll	Sales and/or Revenues
Transportation and Transportation Services			
Water Transportation:			
Steamship companies—personnel afloat	678	$ 8,401,000	$130,000,000
Tug & barge companies—personnel afloat	1,047	9,785,000	48,000,000
Pilotage and berthing services	35	457,000	900,000
Ship chandlers and other vessel suppliers	254	2,401,000	5,692,000
Commercial fishing	675	6,525,000	15,000,000
Repair and construction of commercial vessels	1,527	12,988,000	24,027,000
Subtotal: Water Transportation	4,216	$ 40,557,000	$223,619,000
Surface Transportation:			
Rail	967	$ 9,008,000	$ 18,437,000
Truck	457	4,993,000	13,137,000
Air	10	100,000	500,000
Subtotal: Surface Transportation	1,434	$ 14,101,000	$ 32,074,000
Transportation Services			
Marine construction	189	$ 1,563,000	$ 4,747,000
Physical handling of maritime cargoes (longshore and stevedoring, crating, stuffing & unstuffing of containers, local drayage, and warehousing)	2,585	24,496,000	45,763,000
Administrative activities—private (personnel ashore of steamship and tug & barge companies, freight forwarders, customs house brokers, foreign trade departments of banks, insurance companies, and trade associations)	1,704	14,445,000	8,233,000
Administrative activities—public (Port of Seattle Commission, federal, state, & local agencies, foreign consulates and trade missions)	2,111	20,512,000	47,120,000
Other waterfront related activities (marine surveyors, admiralty lawyers, consultants, maritime labor unions, and news media)	242	3,808,000	4,393,000
Subtotal: Transportation Services	6,831	$ 64,814,000	$110,256,000
Total: Transportation and Transportation Services	12,481	$119,472,000	$365,949,000
Manufacturing			
Food/kindred products	1,400	$ 10,629,000	$ 78,279,000
Wood/paper products	1,689	11,848,000	42,040,000
Metal products	464	3,748,000	13,072,000
Machinery & equipment	2,921	24,715,000	82,483,000
Other manufacturing	2,125	16,865,000	77,546,000
Total: Manufacturing	8,599	$ 67,805,000	$293,420,000
Wholesale Trades	4,320	$ 40,324,000	$ 95,154,000
Grand Total Direct Impact	25,400	$227,601,000	$754,523,000

* From Seattle Maritime Commerce and its Impact on the Economy of King County, Seattle Port Commission, 1971.

Exhibit 2

Estimated Additional Costs for San Francisco Bay Dredging Projects as a Result of Application of E.P.A. Dredge Disposal Criteria*
January 1, 1972 to October 1, 1973

Dredging Applicant	Project Size (Cubic Yards)	Disposal Site Requested	Disposal Site Approved	Estimated Additional Cost
1. Humble Oil	10,000	Carquinez Strait	Alcatraz	$ 9,600
2. USN Hunters Point	170,000	Hunters Point	Deep Ocean	77,000
3. WPRR Oakland	6,000	Alcatraz	Deep Ocean	18,000
4. Bethlehem Shipyard	125,000	Hunters Point	Deep Ocean	220,000
(one project)	25,000	Hunters Point	Alcatraz	9,000
5. Port of Oakland	95,000	Alcatraz	Deep Ocean	113,000
6. Exxon Benicia	80,000	Carquinez Strait	Alcatraz	76,800
7. Schnitzer Oakland	36,000	Alcatraz	Deep Ocean	68,400
8. Corps Oak IHC	900,000	Alcatraz	Deep Ocean	1,440,000
9. Dumbarton Br.	121,000	South Bay	Alcatraz	138,000
10. PG & E Oleum	12,000	Carquinez Strait	Alcatraz	12,000
11. Port of Richmond	10,000	Alcatraz	Land	?
12. San Leandro Mrna	350,000	Hunters Point	Land	?
				$2,181,800

* From Newsletter #6, California Marine Affairs and Navigation Conference, Oct. 30, 1973.

THE PUBLIC'S ROLE

SEA GRANT ESTUARINE STUDIES

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ABSTRACT

Approximately 20 percent of funds dispensed under the National Sea Grant College and Program Act of 1966 (PL 89-688) has been directly related to estuarine studies. Since 1971 $13 million in federal funds, matched by $8 million in non-federal support, has been directed to this area. In the same period 533 projects in support of ecosystems research, coastal zone management, pollution studies, environmental modeling, and applied oceanography were conducted under the Sea Grant Program.

Brief case histories of estuarine related studies in Narragansett Bay, Long Island Sound, the Neuse and Albemarle River Basins, Apalachicola and Escambia Bays, Barataria Bay, Matagorda Bay, and Puget Sound are presented as examples of Sea Grant work.

The applied nature of Sea Grant studies is emphasized by examples of the utilization of Sea Grant estuarine-related research. Particular attention is given to how these studies have been used by local, state, and federal decisionmaking bodies.

A partial bibliography citing 58 Sea Grant reports on estuarine research is presented.

INTRODUCTION

Incubators for much of life in the sea, estuaries are fragile environments, taking sustenance from land and sea in an unending cycle.

Influenced by both land and sea, the nation's estuaries are vital resources of the coastal margins. And the delicate balance of these nursery grounds is further complicated by man's increasing pressure on the coastal zones of this country.

An intricate network of natural phenomena and manmade intrusions converge in America's coastal zones. Each of these has a direct bearing on the estuarine environment. Research to learn more about estuaries encompasses a much broader scope than the estuary itself. One must understand the nature of adjacent bays, the islands which bar the sea from the land, shipping lanes which criss-cross the nearshore environment, freshwater inflows which feed the sea, the biological mysteries underlying the ocean's food chain, the effects of man's use of the nearby land and ocean, and the physical, chemical, and biological parameters of the nearby ocean.

Created to "achieve gainful use of marine resources" through the establishment of sea grant colleges, the National Sea Grant Program has focused a significant effort toward understanding the forces which influence the nation's estuaries. Through a partnership arrangement between the federal government and the nation's colleges and universities, the Sea Grant Program, administered by the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, has directed more than $21 million in federal funds toward marine environmental research since 1971. In 1974, 165 projects were underway along all U.S. coasts and the Great Lakes.

Sea Grant: How It Works

When the Congress created the Sea Grant Program in 1966 (PL 89–688), it was envisioned as a marine resource effort which would be patterned, in part, after the successful land grant program fostered by the Morrill Act of 1862. Whereas the land grant program concerned itself with food production from the land, Sea Grant is concerned not only with food production from the ocean but also with the development and use of other resources—minerals, recreation, transportation, and others—which relate to the sea. To accomplish its mission, by law Sea Grant must carry on work in applied research, education, and advisory services.

Administered by the National Science Foundation from 1966 until the creation of NOAA in 1970, the program is a matching fund arrangement. As much as two-thirds of the funds for Sea Grant programs in universities and colleges come from the federal government with at least one-third coming from

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Table 1.—Sea Grant Program Support by Category of Effort FY71-74

Category	1971 SG $ (MF $)	1972 SG $ (MF $)	1973 SG $ (MF $)	1974 SG $ (MF $)	Total SG $ (MF $)
EDUCATION/TRAINING	1,880,350 (1,937,878)	1,957,700 (1,469,975)	1,483,194 (2,125,273)	1,217,128 (1,869,726)	6,518,372 (7,402,952)
ADVISORY SERVICES	1,096,359 (581,344)	2,184,135 (1,158,523)	2,658,562 (1,389,705)	3,568,695 (1,791,681)	9,507,751 (4,931,253)
RESEARCH					
•Marine Technology Research & Development	1,830,889 (925,890)	3,159,949 (1,794,834)	3,037,103 (1,626,595)	2,941,518 (1,851,898)	10,959,459 (6,199,217)
•Marine Environmental Research	2,652,990 (1,708,638)	3,135,814 (1,707,906)	4,030,467 (2,411,610)	3,384,116 (2,344,411)	13,203,387 (8,172,565)
•Socio-Economics & Legal Research	524,531 (228,905)	845,176 (440,173)	1,115,015 (533,816)	909,659 (624,113)	3,394,381 (1,827,007)
•Marine Resources Development	3,685,288 (2,322,529)	3,665,132 (2,144,644)	4,532,119 (2,813,753)	5,018,347 (3,046,353)	16,900,886 (10,327,279)
PROGRAM MGM'T	904,843 (753,463)	1,390,273 (1,010,114)	1,619,758 (1,052,076)	1,721,477 (1,358,018)	5,636,351 (4,173,671)
TOTALS SG $	12,545,250	16,338,179	18,476,218*	18,760,940**	66,120,587
(MF $)	(8,468,647)	(9,725,169)	(11,952,828)	(12,886,200)	(43,033,844)

*Does not include $857,900 awarded as amendments to grants originating in FY72.
**Does not include $293,000 for 7 awards not requiring matching funds.

institutional sources. This matching requirement has created a partnership between government and institutions which is the cornerstone of the Sea Grant concept.

Since 1971, the program has granted $66 million to universities and others. An additional $43 million has been matched by grantees as shown in Table 1.

Support to institutions from the National Sea Grant Program takes several forms: project support for a single activity; coherent area support for several projects centered around one primary problem; institutional support for programs undertaking work in several research areas and in education and advisory service areas; special designation as Sea Grant College for universities exhibiting excellence and commitment while receiving institutional support.

Sea Grant's intent is to bring many types of expertise into marine-related work. Grantees include scientists, engineers, teachers, lawyers, economists, businessmen, and industrialists. In FY1974 3,796 individuals were involved in Sea Grant supported projects—2,334 full-time equivalents as shown in Table 2.

In 1975 eight Sea Grant Colleges had been named—Oregon State University (1971), Texas A&M University (1971), University of Rhode Island (1971), University of Washington (1971), University of Wisconsin (1972), University of Hawaii (1972), University of California (1973), State University of New York/Cornell (1975).

The Partnership

Since the program is operated to serve state and regional needs, the mechanisms for bringing university resources to bear upon these area problems and needs necessarily include local involvement. A typical university Sea Grant program, for instance, will have several advisory councils or committees helping define the most important problems for study.

Through marine advisory service field agents who live and work in the communities bordering the coast, local problems are identified. These field agents work closely with fishermen, businessmen, port directors, and others who are dependent upon the sea for a living. Through field agents, problems are brought back to the institution. Often information already exists which can help. In other instances,

Table 2.—Individuals Involved in Sea Grant Projects FY 1974

Type	Research	Advisory Services	Education	Total
Faculty/Professional	1,140	325	297	1,752
Graduate Students	562	26	105	696
Undergraduate Students	274	30	101	442
Technicians	307	25	49	355
Clerical	232	80	50	374
Other	99	119	30	177
Total	2,614	605	632	3,796
FTE's	1,742	365	176	2,334

research efforts must be mounted to acquire information needed to make decisions. As information is generated it is fed back to the local areas through meetings, workshops, publications, films, or one-to-one teaching sessions.

Problems may range from the demand for trained personnel to the need for organized workshops on new state or federal regulations. But all are evaluated by local groups and university personnel to arrive at decisions about how solutions may be generated.

Where research, education, or advisory services projects are called for, proposals are written, and evaluated for scientific and technical quality by experienced professionals from the universities, state or federal agencies, private laboratories or industry. Even before the institution submits its comprehensive proposal for federal support, the project has been subjected to many kinds of reviews and judged on its relevance to local problems.

Once the NOAA Office of Sea Grants is asked to support a project, other technical reviews are made, plus a further review is made to determine its appropriateness to the Sea Grant mission. A National Sea Grant advisory panel, composed of knowledgeable individuals from industry and universities, participates in this review process and decides on grants to be made. This panel, with personnel from the Office of Sea Grants, must take into consideration not only the technical quality of the proposal but also the total funding available to the National Sea Grant Program.

Through this process of review and evaluation, projects eventually undertaken as part of the Sea Grant Program are assured of having high technical and scientific quality and relevance to the needs of the local community or state.

MARINE ENVIRONMENTAL QUALITY

Concern for environmental quality and estuarine research is a manifestation of how the Sea Grant partnership works. Sea Grant's chief concern is people, people who work in the sea, live near its shore, or benefit from its bountiful resources, and one of the important concerns of people is the quality of the environment. Sea Grant advisory field agents, working closely with local groups, help identify problems which affect the quality of the coastal and nearshore environment. Local support for Sea Grant projects often shows up as matching dollars for the project. As evidence of the local acceptance of the program, the mandatory matching requirement has exceeded the demand. Forty-one percent of the total Sea Grant funding for the current fiscal year is from matching money.

Table 3.—Numbers of projects by categories FY1971–1974

Category	Numbers of Projects (Total)			
	*1971	1972	1973	1974
RESEARCH AND STUDIES IN DIRECT SUPPORT OF COASTAL MGM'T DECISIONS	(21)	(38)	(58)	(67)
•CZM Social Sciences		13	22	32
•CZM Natural Sciences		25	36	35
ECOSYSTEMS RESEARCH	(13)	(11)	(28)	(25)
•Ecosystems Research		11	28	25
POLLUTION STUDIES	(17)	(46)	(45)	(40)
•Oil Spills		5	3	3
•Pesticides		8	6	5
•Thermal and Radioactive		11	5	6
•Metals		9	5	4
•Other		13	26	22
ENVIRONMENTAL MODELS	(15)	(20)	(23)	(25)
•Physical Processes		9	10	12
•Biological Processes		6	6	8
•Other		5	7	5
APPLIED OCEANOGRAPHY	(16)	(9)	(9)	(8)
•Chemical		2	1	1
•Physical		7	8	7
TOTAL	82	123	163	165

*Project information for FY1971 is available only by major areas of emphasis.

Although there is no specific research category labelled "Estuarine Studies," Sea Grant recognizes the importance of support to all aspects of the nearshore marine environment. Because of the many forces which impact upon the nation's estuaries, studies in several categories are considered vital to understanding the complex estuarine environment.

Work in support of marine environmental quality is carried out in five major areas of emphasis under Sea Grant: Research in Support of Coastal Zone Management Decisions; Ecosystems Research; Pollution Studies; Environmental Models; and Applied Oceanography.[1]

These major topics are further broken down into sub-topics as indicated in Table 3. Work in the coastal zone is clearly the most important area of investigation with 67 projects underway in the 1974 fiscal year. Pollution studies including oil spills, pesticides, thermal, radioactive, and metal pollution, rank second.

For the period FY1971–1974, $13 million in federal funds and $8 million in matching funds have been devoted to marine environmental quality studies. This area of research has received significantly more non-federal support than matching funds required by law. Characteristic of the entire

[1] Under the Sea Grant legislation, the Great Lakes are considered "salty" and studies undertaken in these important waters are included in the tables presented here.

Table 4.—Sea Grant Supported Marine Environmental Research FY1971–1974

Major Emphasis	1971 SG $ (MF $)	1972 SG $ (MF $)	1973 SG $ (MF $)	1974 SG $ (MF $)	Total SG $ (MF $)
Research in support of coastal management decisions	944,947 (742,149)	964,963 (503,835)	1,410,543 (1,037,787)	1,204,180 (1,075,194)	4,524,633 (3,358,975)
Ecosystems Research	599,500 (431,230)	379,984 (275,329)	812,677 (447,061)	563,479 (344,819)	2,355,640 (1,498,439)
Pollution Studies	420,184 (211,910)	1,059,569 (634,723)	810,215 (573,172)	686,184 (426,644)	2,976,152 (1,846,449)
Environmental Models	348,697 (178,677)	533,748 (248,250)	587,683 (200,742)	686,826 (382,208)	2,156,954 (1,009,877)
Applied Oceanography	339,662 (144,672)	197,550 (45,769)	409,349 (152,838)	243,447 (115,546)	1,190,008 (458,825)
TOTAL SG $	2,652,990	3,135,814	4,030,467	3,384,116	13,203,387
(MF $)	(1,708,638)	(1,707,906)	(2,411,610)	(2,344,411)	(8,172,565)
% of all Sea Grants	21.1	19.0	21.8	18.0	

Sea Grant program, this overmatch is evidence of the importance of working closely with local groups to identify problems.

In addition to the research volume as indicated in Table 4, much of the work of marine field agents is directed toward environmental quality. In the period FY1971–FY1974, a total of $14.4 million has been used to build a national network of marine agents. Of this amount, $4.9 million has come from non-federal sources. The strength of this network lies in its ability to work at the local level, to tap the expertise of Sea Grant institutions, and to relate research to the coastal and marine problems of the nation.

Although 165 projects in support of estuarine quality were conducted in FY1974, only a few examples are cited in this report. They are included as indicators of the kinds of local-federal arrangements which Sea Grant endorses and supports.

ESTUARINE RELATED STUDIES

New England

Narragansett Bay.—Sea Grant researchers at the University of Rhode Island are using computers to simulate various processes in Narragansett Bay.

- Ocean engineers have completed a physical model of tides and currents that has been used to predict water quality in the upper bay after a storm sewer overload and the movement of oil slicks from spills in the lower bay.
- Resource economists have developed an economic-ecological model that can be used to predict the effect of economic growth on water pollution.
- Marine biologists are devising a model that will characterize such features as animal and plant populations.

Together, the studies will lead to a coordinated model to show the interaction among the physical, biological, and economic aspects of man's use of the bay.

The physical model of the bay is based on laws of fluid motion and takes into account the effects of tides, storms, and the earth's rotation. It can predict water movement in the entire bay or at any one of 320 separate points.

It has been used to compute temperature profiles for the heated water discharge of a proposed nuclear power plant. The profiles indicate to what extent bay water would be affected by the effluent and provide clues to its potential effect on marine life.

Again using the physical model, Sea Grant scientists have been able to predict the dispersion of past oil spills, knowing only their size and location, with significant accuracy. Such predictions can help officials anticipate where a spill might spread and can be used to evaluate the effectiveness of oil spill contingency plans.

The resource economists' model of the bay can be used to predict increased pollution from new economic activity. The calculations consider wastes which result directly from increased production as well as those generated by supporting industries.

In addition to research that examines the bay as a whole, other URI Sea Grant work on the environmental impact of marinas in small inlets has led to recommendations that new marinas be located where tides or currents flush the area frequently.

In the first major study of a New England salt marsh in about a decade, Sea Grant scientists have

completed an intensive ecological study of a small salt marsh embayment on the west side of Narragansett Bay.

Measurements of major populations, their metabolism, and seasonal patterns of the total salt marsh metabolism were made to ascertain energy flow within the embayment. The scientists simulated additions of sewage and heated effluent water to the salt marsh inlet. They concluded that sewage from a housing development around the marsh would lead to total depletion of dissolved oxygen in the marsh waters and that the introduction of heated water, such as power plant effluent, would cause small, but measurable lowerings of dissolved oxygen.

Long Island Sound—Using a mathematical model in New York, researchers with the State University of New York (at Stony Brook) are testing management schemes for improving water quality in Long Island Sound. One idea being evaluated could lead to better flushing of the western end of the sound and New York Harbor. It calls for building gates, or locks, across the upper East River, a major source of pollutants in the once-productive sound.

At ebb tide in the East River, the gates would be open to allow unhindered flow of clean sound water through the river, down into New York Harbor, and out into the New York Bight. Six hours later, at slack water, the locks would be closed, blocking the flow of polluted harbor and river waters back into the sound. After another six hours, the gates would be reopened to repeat the cycle.

Tests of the tidal flushing scheme with the model indicate that sewage concentrations would drop 78 percent in the western end of the sound and 50 percent in New York Harbor. The predictions assume that half the East River sewage now enters the sound.

South Atlantic

Neuse and Albermarle River Estuaries.—Sprawling between North Carolina's mainland and its Outer Banks are 2.6 million acres of sounds and estuaries, an area which ranks near the top of the state's list of most valuable resources. The North Carolina Sea Grant program conducts research aimed at contributing to the state's ability to make sound policies concerning the estuarine environment.

Scientists at the University of North Carolina are tracing nutrients—nitrogen and phosphorus as they travel into and through the estuaries to determine the effects these nutrients have on the resource. Computers are used to map changes in the estuarine waters throughout the Neuse and Albermale River estuaries. These maps also show changes in the estuaries over time.

The research has provided evidence that oxygen concentrations often drop in the summer, as algae blooms thrive and salt water settles to the bottom. Fish begin to migrate out of large areas where oxygen is low, leading scientists to believe more nutrients in the estuaries could lead to longer periods of low oxygen. Such periods could be harmful to fish and organisms that cannot leave the waters.

State agencies that must monitor and control water quality are using the information derived from these studies to gauge the impact of upstream sources of sewage and nutrients on the estuaries. Already Sea Grant researchers have recommended maximum temperature standards for industrial effluents to officials formulating water quality policy.

University of North Carolina teams also are undertaking work to learn more about the soils in the estuarine environs and the processes which shape the state's shoreline. The state's barrier islands and the rest of its coastline are threatened by erosive forces of ocean waves and currents.

Meanwhile, another research team is using Hatteras Beachgrass, a variety developed by NCSU soil scientists several years ago, to stabilize dunes. Advantages of the Hatteras grass include its hardiness. Where only five percent of American beachgrass test plantings survived the first year, the survival rate for Hatteras jumped to 70 percent.

In a related activity, the soil scientists joined with the Corps of Engineers in a project to stabilize the soil which is dredged from rivers and channels. They have found that it is possible to build productive marshlands from the dredging spoils in some areas.

In field studies and with the computer, University of North Carolina Sea Grant scientists have traced water flow through the state's tidal inlets and sounds. Field research focused on water circulation in the Oregon Inlet and Croatan-Roanoke Sound areas and in the Neuse River estuary. Using the computer, NCSU civil engineers modeled water quality, surface-elevation, and water movements in Pamlico Sound under various conditions including hurricane winds. A water quality model of the Neuse River estuary has been verified with field data. Information gained in both the field and computer studies is useful in predicting water flow and water quality and can provide valuable information for resource management decisions.

Gulf Coast

Apalachicola and Escambia Bays.—Apalachicola Bay and its drainage system are important concerns

to nearby coastal counties. Franklin County, for example, is economically dependent upon the finfish and shellfish resources of the bay, which produces over 80 percent of Florida's oyster crop. Researchers from the State University System of Florida, studying the possible effects of the agricultural chemical Mirex, provided data from their Sea Grant work to the state's Department of Natural Resources Endangered Land Task Force, to the EPA, and to the Florida House of Representatives.

The team was asked to expand the scope of the project on Mirex, a chemical used to control fire ants, to include the productivity and water quality in the bay's drainage system. Funding came from the Franklin County Board of Commissioners and the Florida Department of Pollution Control.

Based on data from the Sea Grant research project in Apalachicola Bay, the State of Florida is purchasing 17,000 acres of land at a price of $4.2 million.

Data collected in Apalachicola Bay will be compared with information derived from another study in Escambia Bay which has gained national attention in recent years due to a series of devastating fishkills symptomatic of deteriorated water quality.

As part of an interagency task force established by an EPA conference in 1972, Sea Grant is involved in efforts to reverse the bay's deterioration and guide the recovery process. Data from the project has already been used in planning for a projected 30 percent population increase for the Pensacola metropolitan area over the next 15 years.

The importance of studying interrelationships between and among bays has been documented in the project. Under certain conditions, for instance, Pensacola Bay bottom water moves into the East and Escambia Bays. Knowledge of this movement is important in predicting movement of sludge out of Escambia Bay and in determining sites for waste outfalls. The study has already provided data to state officials in the development of a wastewater management plan for the drainage basin.

The data has also been used in evaluating an oil-drilling permit request and by real estate interests in coastal development.

Barataria Bay.—Initiation of Louisiana's Sea Grant program in 1968 gave Louisiana State University scientists their first opportunity to mount a major multidisciplinary study of the state's fragile and fertile coastal marshes—seven million acres of estuaries and wetlands.

In early 1969 field activities began on the Barataria Bay Project, named for a major bay-marsh complex in southeastern Lousiana. Wild Life and Fisheries Commission personnel describe the area as the most biologically productive estuary in a region acknowledged as the major nursery ground for commercial fisheries in the northern Gulf of Mexico.

Initial studies were made at widely dispersed locations to assess factors that varied spatially, such as salinity and vegetative types, as well as those that changed with tidal stage and season. The investigation has since been extended to the littoral zone from the Mississippi River mouth to the offshore area of the Barataria Bay system and to various marsh types and swamps. The results showed that the marshes and swamps play the key role in organic production necessary for nutrient generation in situ and in sediments in Barataria Bay system. Nutrients to the Barataria from the Mississippi River are limited to high flooding stage of the river in early spring, but the river flooding inundates the entire nearshore zone of the Louisiana coast with vast amounts of organic matter and inorganic nutrients annually from winter to late spring. Under investigation is the influence of the Mississippi flooding on the chemical parameters of water and sediment in the major oyster producing area east of the river, in relation to oyster growth, quality, and condition for parasite infection.

Perspectives gained from the first several field seasons led investigators to formulate a detailed plan for study, synthesis, and operational research of the total estuarine ecosystem. They have already characterized estuarine productivity by means of a detailed model and energy flow data.

This synthesis of nutritive processes will provide a scheme by which the relative importance of every consumer species in the marsh, as well as the marsh plants themselves, can be assessed in terms of utilization of commercially important shrimp and fish. Further, through estimates of plant material flushed into open waters, the contribution from coastal marshes to offshore food chains can be examined. From this information, economic questions concerned with alternate uses of the estuarine marsh and its living resources can be examined rationally.

Knowledge gained from the project has already been used to evaluate the impact of man's activities—primarily oil production related—and will later lead to recommendations for management practices in Louisiana's coastal region.

Matagorda Bay.—An example of the comprehensive approach Sea Grant researchers take toward estuarine studies is Texas A&M University's four-part resource evaluation of the Matagorda Bay area.

The study was undertaken to complement work

done for the General Land Office of Texas by the Texas Bureau of Economic Geology. It is part of a continuing quest for information upon which to base coastal policy decisions.

Texas A&M's study, supported by the General Land Office and industry, involved an interdisciplinary team of geologists, biologists, oceanographers, and economists.

The team focused on water circulation patterns and their effect on coastline change and pollution dispersal; on chlorinated hydrocarbon levels in bay sediments; on the validity of interpreting environmental factors from the presence of skeletal remains of certain marine organisms; and on the economic structure of the bay area and the probable economic effects on changes in population, resources and transportation.

Pacific Northwest

Puget Sound.—In Washington, Sea Grant has supported several projects to provide impartial data for policy makers who must make coastal zone management decisions while beset by intense pressures from competing interests.

One effort by an interdisciplinary team of University of Washington economists, oceanographers, political scientists, and public affairs specialists, is a series of case studies of public controversies over potential uses of Puget Sound shorelines. The result is a major reference work on management of a large estuarine-inland waterway system.

Concern over discharge of sewage sludge from Seattle into Puget Sound led Sea Grant scientists to construct a mathematical model that describes the effects of environmental factors upon phytoplankton growth in the sound. With support from EPA, a quantitative description of the main features of mid-channel circulation in the central basin of the sound was developed. The results were used to calculate algal population dynamics and to identify and describe environmental factors which control algal growth.

The Washington Sea Grant Program has a major publishing venture underway to present, in readily accessible and usable formats, data on the marine environment of Puget Sound collected over the past 40 years. Produced with support from the Washington Department of Ecology, the materials are believed to be of great value to regional resource planners.

State and local management agencies are responding to recent EPA requirements for water quality in Puget Sound. Estimates by some Washington groups place the cost of basic data accumulation at more than $4 million. The Seattle metropolitan area (Metro-Seattle) has committed $1.1 million in local funds for studies on waste disposal. Baseline studies will be funded by the state.

TRENDS AND IMPLICATIONS

Since local and state governments hold key managerial roles in the nation's coastal zones, including responsibilities for estuarine areas, the tie to these governmental units is the Sea Grant Program's greatest strength.

As indicated in Tables 3 and 4 of this report, research and studies in direct support of coastal management decisions have grown steadily since 1971. With the passage of the Coastal Zone Management Act of 1972, state agencies and Sea Grant institutions have devoted even greater time and effort toward these important land and water areas. Not only has the federal Sea Grant support for coastal management decisions increased in the past two fiscal years (Table 4), but matching funds have amounted to approximately 43 percent of the total spent, making a cumulative expenditure of $7.8 million since 1971.

Pollution control and ecosystems research, on the other hand, has declined during the same period. Sea Grant Program directors at several universities see this as a continuing trend. They reason that pollution studies for example, have been designated as part of the EPA mission and with federal appropriations for Sea Grant programs growing slowly, the funds available must be directed to problem areas where other federal agencies have not been given responsibilities for granting and contracting.

With the creation of guidelines for state support under the Office of Coastal Zone Management, NOAA, states are beginning to plan ways to implement the coastal management law. With federal guidelines clearly asking for state management programs, the Sea Grant funded work which has already been done in many of the coastal states is proving invaluable, cementing the university-state-federal partnership.

In Rhode Island, for example, one of the first states to pass comprehensive coastal management legislation, the University of Rhode Island's Coastal Resources Center has been designated as the research arm of the Coastal Resources Management Council. The first fact-finding mission of the Center resulted in recommendations for the use of the state's barrier beaches. Based on research supported by Sea Grant, the Center made recommendations on construction and vehicle traffic which provided the basis for state beach regulations.

In other states, too, Sea Grant programs have developed supporting data upon which state agencies can begin to develop management plans. At the University of Michigan, a valuable review of state coastal management programs was prepared early in 1972, even before the federal coastal zone act was passed. Summaries of state coastal management programs were examined, including estuarine and wetlands preservation measures. The comprehensive examination of selected state programs became a valuable information source for states seeking coastal zone legislation.

In 1970, the Oregon State University Sea Grant Program prepared and distributed thousands of copies of a report entitled "Crisis in Oregon Estuaries" which reviewed the value and vulnerability of these natural resources. Fourteen major estuaries were discussed with special emphasis given to their present and potential contributions to the state's economy and the threats posed to the economy by misuse and poor management practices. The State of Oregon shortly passed coastal zone legislation encompassing all areas west of the coastal mountain range. Sea Grant also helped prepare the impact statement which led to the designation of the South Slough of Coos Bay as the nation's first (and only, at this writing) National Estuarine Sanctuary.

Stimulus for Public Decisions

Proper management of natural resources involves understanding all the ramifications of any given move—as in a game of chess. And the University of Michigan Sea Grant Program tackles resource management problems exactly that way. In fact they developed a game so stimulating that it is used by regional planning commissions and other state and local officials to help them see the consequences of decisions they make in coastal and water resource planning.

Called WALRUS (Water and Land Resource Utilization Simulation), the game was developed to provide a means of communication and interaction among the Sea Grant scientists and the public that they seek to serve. Played with four or five teams of about five members each, the players represent different economic and geographical interests. As the game progresses they learn that no matter what decisions they make, the environment is going to reflect them—for good or for bad.

All along the Sea Grant network, scientists and research managers are seeking closer interaction with state agencies and public officials. The purpose: to bring well-developed information into the decision making arena. A survey of Sea Grant programs reveals many examples of the results of such relationships:

- In New York, findings of seven Sea Grant projects assessing the state's power plant siting practices have been presented to the State Department of Environmental Conservation, the Public Service Commission, the Governor's Office and the Legislature. The information is being used in testimony at both state and federal hearings.
- In a report for the California Coastal Zone Commission entitled "Governing California's Coast," the University of California Sea Grant Program has analyzed alternative mechanisms for carrying out the state's coastal zone management plan. The Commission's policy on water quality and pesticides is based on work by Sea Grant researchers at the University of Southern California.
- In Florida, Sea Grant supported work in the University of Miami's Ocean and Coastal Law Program has contributed to passage of legislation designating Biscayne Bay as the state's first marine preserve area and to the Florida Coastal Mapping Act, the first of its kind in the nation.
- The Louisiana Coastal Zone Statute, pending before the state's legislature, was drafted for the Louisiana Advisory Commission on Coastal and Marine Resources with Sea Grant support.
- The Senate Report "Papers on National Land Use Policy Issues," incorporated information developed by the MIT Sea Grant Program.
- University of Rhode Island Sea Grant researchers have been involved in formulation of state marine sand and gravel regulations, a barrier beach plan, and in the preparation of other information needed by legislators.
- In Texas, for instance, a series of small workshops in 1970 eventually led to the state's first major conference on marine and coastal resources—one called by the governor of the state. Out of the meeting came recommendations for state action which have since led to the creation of a Coastal and Marine Council and several legislative committees. Later, Texas A&M Sea Grant work on deepwater terminals had a direct influence on the creation of a state Offshore Terminal Commission. Work now underway on the Gulf Intracoastal Waterway has been instrumental in developing public hearings on the use of the waterway.

In a number of states Sea Grantees serve on commissions or councils responsible for policy making in marine and estuarine matters. States having such arrangements include Texas, Oregon, Massachusetts, Louisiana, Rhode Island, Washington, and Hawaii. In other instances Sea Grantees hold

appointments on national marine councils and are active in committees of the National Academy of Sciences and Engineering.

Sea Grant's presence is also felt in local communities through a number of other channels—workshops for teachers, 4-H meetings, civic club lectures, television and radio programs, films, bulletins, newsletters and special publications, atlases, maps, meetings and conferences. Through its research, education, and advisory service components in more than 50 colleges, universities, and other institutions, Sea Grant hopes to bring about a greater public awareness of the importance of marine and estuarine resources.

Coordination with Other Agencies

Interaction with other federal agencies is achieved through strenuous review process for all Sea Grant supported research. Written reviews are required for all projects and representatives of federal agencies involved in marine-related activities are present at annual reviews conducted on university campuses. These site visit teams conduct an indepth evaluation of work underway as well as the work proposed for the coming year. Typically, site visits have representation from one or more of the following agencies: National Marine Fisheries Service, EPA, U.S. Army Corps of Engineers. Written reviews are solicited from these agencies as well as the Office of Education, HEW, and the National Science Foundation.

Interaction with the Research Applied to the Needs of the Nation (RANN) program of NSF has resulted in routine exchanges of proposals.

Within NOAA, the Office of Coastal Zone Management and the Office of Sea Grants coordinate granting and contracting arrangements. The closeness of these two programs makes frequent interaction imperative.

At the state level, program and project reviews are solicited for some research projects. At most university site visits, local representation is arranged. Among the groups asked to review the research programs are representatives from state departments of natural resources, fish and game commissions, state planning offices, marine councils, navigation districts, port authorities, county commissions, and regional councils of government. Sea Grant institutions also seek participation of these groups, along with industrial and academic representation, on their own advisory councils.

As a result of the careful scrutiny given to research proposals, the work undertaken by Sea Grant programs is technically feasible and locally acceptable. This continuing review process assures that universities are meeting the needs of the state without duplicating efforts of other agencies.

CONCLUSION

Careful study of Sea Grant work in support of estuarine quality leads to several observations about future work and about the Sea Grant concept in general.

As American universities struggle through their current identity crisis, many new thrusts are likely to emerge. The university of the future, for example, may assume several roles—an ivory tower of knowledge, a processor of trained professionals and skilled craftsmen, a generator of new knowledge through basic research. In all of these roles, however, the university will become more of an agent for social change, a medium for transmitting information designed to improve the quality of life. In this regard, the university will assume greater responsibility for applied research, blending together old and new knowledge and delivering better alternatives for future decisions. This trend is already emerging, particularly in state-supported institutions; and through partnerships such as Sea Grant, the pace is accelerated.

This trend has been brought about, in some degree, by the recognition of state and federal agencies of the manpower and knowledge resource which universities represent. Tapping these resources is a logical mechanism for tackling many state and national problems. With each new generation of students adding to the knowledge base, universities remain at the forefront of knowledge. As students, professional teachers, and researchers extend themselves into applied and decision-oriented research fields, the total university resource can be brought to bear on identified needs.

The preceding examples of Sea Grant work in environmental quality are evidence of the future of university-based programs which draw together teams of professional scientists, engineers, and social scientists to focus on broad resource issues. The studies are also illustrative of the impact potential when partnerships exist between federal and state interests.

Although much has been accomplished under the Sea Grant banner, its greatest contribution lies in the innovativeness of its approach and the spirit of service which it has sparked in American colleges and universities.

REFERENCES

The citations listed here are representatives of the estuarine related publications resulting from Sea Grant supported work. The list does not include all publications which support estuarine studies; it is intended as a sampling with particular emphasis on the studies cited in the preceding report.

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ESCAROSA: THE ANATOMY OF PANHANDLE CITIZEN INVOLVEMENT IN ESTUARINE PRESERVATION

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ABSTRACT

Florida's gulf coastline measures over 700 statute miles, and has the most diverse estuarine flora and fauna of any state. Because of its growing population and its readily accessible coastline probably no other estuarine system has received pressures comparable to those exerted on Florida's gulf coast ecosystem from 1950 to the present. This paper revolves around the "Florida Panhandle" in general and Pensacola in particular.

Citizen involvement begins through information services provided by newspaper, radio, and TV. In Pensacola, the newspaper media had the greatest impact and long-term effect.

There are a variety of vehicles and mechanisms for citizen involvement and many were brought into play in the panhandle. One of the most effective approaches is through sportsmens' organizations. Homeowners' associations also can be effective vehicles, but they may be self serving and are more subject to varying levels of bureaucracy. Regional planning organizations are a proper vehicle but they are even more dependent upon and subject to government bureaucracy. Governmental advisory groups can be effective if they can maintain good relations with the board that appoints them and if they can understand that governments cannot correct overnight the damage done by poor planning through decades. Regional, state, and federal hearings are an excellent outlet for citizen pressures.

It is concluded that the Regional Planning Council should be the lead agency in coordinating citizen efforts in estuarine preservation.

INTRODUCTION

Florida's gulf coastline measures over 700 statute miles and has the most diverse estuarine flora and fauna of any state in the United States. The reasons for this diversity are the extraordinary environments and climates found over the 700-mile span. The southern tip of Florida is a drowned lacustrine plain characterized by mangrove swamps and lagoons with lush marine-grass meadows. The mean air temperature is 70°F. in January and 83°F. in July.

Stretching northward from Cape Romano, the coastline changes to barrier islands, sand beaches, and low dunes. Mangroves, tidal marshes, and submarine meadows are major features in the area which also encompasses two major bay systems: Charlotte Harbor and Tampa Bay. The area northward from Anclote Key (Tarpon Springs) is primarily tidal marsh and submarine meadows. The fourth area, and the setting of this particular discussion, is the panhandle of Florida, characterized by barrier islands, high energy beaches, tidal marshes, and numerous bays. The mean air temperature of this fourth area is 53°F. in January and 82°F. in July.[1]

Because of Florida's growing population and consequent development along its readily accessible coastline, there is probably no estuarine system in the nation that has received the pressures suffered by Florida's gulf coast ecosystem from 1950 to the present.[1,6] The locality for this scenario detailing citizen response to estuarine degradation shall be limited to the area entitled "the Florida Panhandle" and centers primarily around Pensacola and Escambia Bay. This area was the site of five federal-state enforcement conferences between 1970 and 1972.[2,6]

The plight of Escambia Bay has received nationwide publicity with newspaper stories and pictures appearing from Los Angeles and San Francisco in the west to Trenton, N.J., in the east.[7,9] In addition, Sports Illustrated classified the Escambia River as one of the nation's 10 dirtiest rivers; Skin Diver magazine's environmental editor, Bill Barada, featured an article on the Escambia story called "Death Trap."[10] Yet all of this publicity is anticlimatic to the roles played by citizens in the area, aroused citizens who already had been doing something about their dying estuarine ecosystems.

The purpose of this paper, then, is to discuss the efforts and achievements of individuals and citizen groups in their struggle for estuarine preservation

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and the improvement of water quality in northwest Florida. My attempt is to show that citizen involvement has been effective even when it was isolated, unpopular, or smothered by red tape; that citizen action has resulted in positive action which makes the outlook for effective preservation much brighter today than six years ago. I treat the various efforts or groups one-by-one not only for convenience but also for the fact that very little integration of effort or interaction initially took place. I conclude the paper with a recommendation for a means to achieve coordinated, effective, continuous estuarine preservation in the area emphasized.

THE ROLE OF MASS MEDIA IN CITIZEN INVOLVEMENT

Whereas nationwide publicity cited above aroused interest and anger in far-flung corners of the United States, major credit for local citizen awareness should go to the staff of the Pensacola News-Journal. A review of newspaper listings from 1962 through early 1970 tells a very complete story of a responsible press coverage: in 1962, one article; in 1963, seven pertinent articles; in 1964, 13 pertinent articles; in 1967, more than 20 articles detailing growing population problems; in 1968, more than 60 articles and thought-provoking editorials; in 1969, more than 200 continuing stories and editorials detailing the day-to-day castastrophies of Escambia Bay.[12]

Pensacola newspaper reporting by Mike Albertson and Tom Bell together with thoughtful editorials and editorial cartoons directed by Earle Bowden brought awareness and education to the citizenry of the two-county area known as Escarosa. These three men are, in the author's opinion, primarily responsible for providing the major impetus for environmental awareness and continued citizen involvement.

By 1970, the electronic media, both radio and television, began to focus on the problem and open the door to citizen involvement. Of particular note and value was the coverage of station WEAR-TV, an ABC affiliate; not only were viewers exposed to the fish kills in the area waters but also to the subsequent federal-state hearings on their causes and on water pollution in general. That citizen response began to increase could be measured by a radio program, "Pensacola Speaks," carried by station WCOA. Listener after listener, night after night, lamented the pollution problem and asked what might be done. In addition, educational television station WSRE (Channel 23) carried panel discussions on the pollution question simulcast with "Pensacola Speaks."

ILLUSTRATION 1

VEHICLES AND MECHANISMS FOR CITIZEN INVOLVEMENT

The following discussion will highlight failures and successes of efforts to prevent or correct what might be called the Escambia catastrophe. In addition, it will briefly mention various vehicles and patterns for citizen involvement.

Sportsmen Organizations

In 1968, a group of interested saltwater fishermen organized the Northwest Florida Sports-fishing Association. The membership swelled to considerable

ILLUSTRATION 2

size and a major thrust was to bring about solutions to estuarine degradation in the area. Its principal purpose was to be a pressure group and to a limited end it was successful. However, the association was unsuccessful in raising sufficient funds to get an unbiased study of bay and estuarine pollution. It is difficult to pinpoint the disintegration or demise of the organization, but it coincides with the intervention of federal investigators in the pollution of Perdido and Escambia Bays and the formation of the West Florida Natural Resources Council. Perhaps this sports fishing association felt it had served its purpose; at any rate, citizen involvement began with it in 1968.

Whereas the Northwest Florida Sports-fishing Association began in 1968 and died in 1969, another group of sportsmen were growing concerned about estuarine preservation. The Bream Fishermen Association (hereafter referred to as BFA) was a small, close-knit group of outdoorsmen dedicated to good practices of wilderness protection, preservation, and conservation. These were not men who would be content to be a pressure group only; they were citizens with definite plans of action. They launched their first efforts on behalf of the national seashore in 1969 and received their baptism of political fire from members of the Santa Rosa Island Authority who objected to their attempts to get petitions signed by the citizenry visiting the beach. Their next major effort was in early 1970. They felt that there was too much talk and not enough action concerning actual biological conditions in the once fertile interface between Escambia River and Escambia Bay. During April, May, and June, 1970, the BFA spent over a thousand man hours conducting a voluntary creel census to document fishing and its results on the Escambia River—a task long neglected by any state agency. The results and conclusions of this census were far-reaching and the enthusiasm of the association recruited new citizen-scientists to its cause. The results were made public in 1971.[13] In a nutshell, analysis of 1,234 different fishing trips involving 2,558 fishermen showed that the average fisherman would catch one fish for two hours' effort and its average weight would be less than a quarter pound! This creel census was only a starter, however, for the BFA also set about to correct matters in an amazingly effective program for 1970.

Convinced that the conditions in the lower portion of Escambia River could be improved by several means, the BFA (1) started a night pollution control program, (2) bioassay stations, and (3) a fish feeding program.[14]

The night pollution program was not just a militant conservation group's idea of harassing industry. The BFA knew full well that the state agency responsible for monitoring pollution simply did not have enough manpower to be everywhere at once—especially at night. A keynote of BFA's success was early detection of a break in a flyash holding pond at a local, coal-burning electric power plant in December, 1970. Along the same lines, bioassay stations were established and maintained in and near industrial outfalls. In both cases, recorded data was turned over to the responsible parties involved. The fish-feeding program stemmed from the

fact that water quality was so poor that fish either would not spawn or, equally bad, their fry would not have sufficient food. BFA members bought over 2,000 pounds of commercial fish food and distributed it on the spawning beds.

In appreciative response, local merchants applauded BFA's courageous efforts and donated a new fiberglass boat, an outboard motor, gasoline, oil, and boat landing services. BFA and its citizen army was on the move.

In the spring and summer of 1971, the "night patrol" turned into the "dawn patrol" as BFA monitored the tidal marsh headwaters of Escambia Bay, collecting data on dissolved oxygen temperature and fish kill conditions. Not only were actual fish kills located in the bay, but also an early warning system was devised. This monitoring program was maintained through 1973 and resulted in valuable data concerning tidal flushing (stagnation) by upper bay waters which infiltrate the tidal marshes.[15,16]

During 1972, BFA made a major effort over a one-year period to document species diversity in the river immediately below the Jay Oil Field adjacent to the Escambia River in north-central Santa Rosa County. With the help of a grant from Humble Oil to the University of West Florida, the association developed a complete faunal inventory of the potential impact area. Such information is not yet generally available but will be of considerable value in assessing the impact of an oil spill on the upper estuarine area. In this project, 40 BFA members worked a total of 3,489 hours in the field![17,18]

BFA activities continued to mount in 1973. Members discovered that yellow bullheads in the Yellow River system are subject to an important melanoma cancer, a fact that proved of interest to both the Environmental Protection Agency and the Smithsonian Institution. During the Oil Field Study, BFA took coliform samples in the river to establish coliform levels and origins prior to bay entry. Members acted as environmental lobbyists to prevent Getty Oil Company from exploratory drilling in East Bay, and the association alertly filed protests with the EPA in Atlanta concerning proposed expansion of Pensacola's northeast treatment plant which was already discharging into an overly-enriched Escambia Bay. This timely protest resulted in the decision that the northeast plant cannot be expanded without concurrence and approval of EPA and the approved Water Quality Management Plan being prepared for the two-county area through the Regional Planning Council.[18]

The year 1974 brought even greater BFA activity in estuarine preservation. BFA members gave material assistance to the EPA Escambia Bay Recovery Team by providing manpower for transplanting marine grasses in the upper estuary. On another cooperative front BFA members aided the Department of Pollution Control by collecting sorely needed data on Perdido River and Bay.

On the lobbying front, the organization has been very effective on several issues: (1) diking Yellow River flood plains; (2) continuing opposition to expansion of Pensacola's northeast treatment plant on Escambia Bay; (3) writing formal objections to the Corps of Engineers on matters of estuarine resource preservation; and (4) filing a court injunction resulting in a favorable ruling against the introduction of "Asian Grass Carp" into Deer Point Lake on the grounds that this species could easily escape from that system and enter northwest Florida's estuaries.[19,20]

In summary, the Bream Fishermen Association's efforts prove that sportsmen organizations can be successful in activities involving estuarine preservation. The key ingredients in these activities are leadership, initiative, and energy. As demonstrated above, the BFA, a citizens' organization, has taken an exemplary leadership role in working in the field with local, state, and federal agencies; in keeping citizens aware of threats to northwest Florida through its "Conservation Newsletter" and displays at the county fair; and in political lobbying.

Homeowners' Associations

Although it may be argued that homeowners' associations, like industries, have a vested interest in estuaries, homeowners on estuarine bayous, bayfronts, and waterways seem to be positively motivated toward good water quality. In the panhandle area we can document some interesting cases of homeowner involvement with estuarine preservation.

Mulatto Bayou-Avalon Beach homeowners.—The mouth of Mulatto Bayou, a bayou historically important as a nursery area on the east side of Escambia Bay, was severely altered in the construction of Interstate 10 bridge across Escambia Bay.[20] After completion of the project, a new access to the bayou was provided. Homeowners in the area, however, used various means of political pressure and lobbying to get the State of Florida to correct silting in the bayou proper.[21] They argued, incorrectly I believe, that the construction activities had caused the main portion of the bayou to become silted in. I met with the homeowners and showed them reasonable proof that the origin of their problem was not road construction, but improper dredging activities

by a real estate developer. After a great deal of discussion, the homeowners became aware that the desired dredging could create even more damage to the system which they wanted so desperately to correct.[22] But their awareness and understanding came too late. The State Department of Transportation had already let bids and issued a contract to an out-of-state dredging company.[23] Last minute letters to state agencies involved were fruitless.[24] Although a hearing was held at the request of the Federal Water Pollution Control Administration because the dredging would be in violation of conferees' rulings, the Corps of Engineers did not cancel its permit and the Mulatto Bayou area was dredged, with disastrous results.[25]

In this example, the homeowning citizens had the best of intentions; their efforts, however, resulted in a death blow to a system struggling to survive.

Perdido Bay homeowners.—Perdido Bay receives a large amount of effluent from a kraft pulp plant located at the head of the bay. Perdido Bay also has received large amounts of poorly treated sewage through Bayou Marcus Creek. The bay is divided by the state line of Florida and Alabama. Although the kraft mill waste and sewage originate in Florida, Alabama residents headed by Mrs. JoAnn Allen strongly have contended and demonstrated that these pollutants reach their shores. Mrs. Allen has courageously maintained pressure not only on officials in Florida and Alabama but on federal officials in Atlanta, Ga., as well. Her efforts were at least partly responsible for Alabama's request for a full-scale investigation in 1969 and continued hearings into the present. Although some of the problems are not fully corrected, the water quality of Perdido Bay is markedly improved as a result of the continuous vigilance and relentless lobbying of this untiring Alabama resident.[2,4]

Bayou Texar Association of homeowners.—Bayou Texar is an estuarine subsystem of Pensacola Bay. It is within the Pensacola city limits and receives its primary sources of freshwater from Carpenter's Creek whose headwaters are outside the city limits. To begin with, Carpenter's Creek has been severely abused by channelization and suburban development. In addition, it is a major recipient of septic tank seepage, lift station overflow, storm sewer drainage, and ordinary runoff from streets, yards, and parking lots. As a result, it has in the past 10 or 15 years carried an immense load of silt, organics, and elemental nutrients into the bayou proper. A worsening situation compounded by outdated sewer lines and a malfunctioning lift station caused the homeowners around the bayou to begin lobbying city government for environmental relief. In addition, they approached the University of West Florida for guidance and scientific advice[26] and provided funds for small-scale research. With the Bayou Texar Association research funds behind him, and the association endorsing him, Dr. Gerald A. Moshiri of the university succeeded in capturing the interest of the Office of Water Resources Research (OWRR) on the causes of nutrification.[27,29] But even after basic research was funded by OWRR, the association members did not rest their case. They have donated time, space, and facilities for the completion of the research. Further, they have maintained their pressure on both the city and the county to correct the problems in the drainage basin and around the bayou. In addition, they have secured a special engineering study designed to provide some approaches to the restoration of a severely damaged estuarine area.

Woodland Lake homeowners.—The Gulf Breeze peninsula is a large finger of land projecting westward into Pensacola Bay. At its westward extremity are three bayou ecosystems: Hoffman's, Gilmore's, and Woodland Lake Bayou. As eutrophication levels in Escambia Bay and Pensacola Bay reached peaks, their nutrient-rich waters began to permeate and stagnate in these estuarine bayous. Following the lead of the Bayou Texar Association, the Woodland Lake homeowners approached the university in 1971 via Dr. Sneed B. Collard of the biology faculty.[30] Through Dr. Collard, a scientific approach to restoring the bayou was designed. With methodical care, the Woodland Lake Association began the necessary lobbying process through local, state, and federal officials. Records indicate that the Corps of Engineers generally investigated the restoration project but could not fund it.[31] The state Department of Pollution Control endorsed it as a "model project" and commended it to the Environmental Protection Agency.[32,33] The regional office of EPA seems to have liked the proposal and forwarded it to the Washington office.[34] After over a year of revising, endorsing, revising, and resubmitting, all came to nought when the Washington office of EPA notified the city of Gulf Breeze that "the model project" endorsed by so many "does not directly fulfill our high priority research needs" and that they could not support the project.[35] This was the culmination of almost two years of citizen effort. A less dedicated group of citizens might have given up, but not these.

The city of Gulf Breeze still backs the bayou restoration and the citizens themselves are putting

their dollars and their hands to the task of clearing the choked opening to the bayou that has developed. After natural flushing is restored, the members must face the benthic sludge problem and the long, slow process of removing it. Their optimism is overwhelming—they will restore Woodland Lake Bayou in spite of the odds and the bureaucratic heartbreaks over the months. They optimistically look for the day when the shrimp and fish return to their restored estuarine ecosystem.

Regional Planning Organizations

West Florida Natural Resources Council.—Formed in June, 1969, by executive order of Governor Claude Kirk, Jr., the West Florida Natural Resources Council (WFNRC) was an ambitiously precocious attempt to establish coastal zone management in the Florida panhandle. It probably grew out of (a) the obvious conflicts in coastal zone use; (b) the very thought-provoking editorials of the Pensacola News-Journal which called upon the University of West Florida for leadership in environmental investigation;[36] (c) the interests of an estuarine-oriented biology faculty; and (d) the farsightedness of Dr. Harold B. Crosby, its first chairman. In a presidential memo dated July 8, 1969, Dr. Crosby, former president of the University of West Florida, explained to the faculty, "Many factors combined to make it necessary and desirable to establish such a council. Amongst them is increasing concern of the people of West Florida over water pollution and the apparent changes in physical and biological quality of the coastal and estuarine environment." The charges to the council were specifically as follows:

1. To establish in the West Florida region at the earliest practical time, under the control and supervision of the council, task forces to recommend and implement plans:
   (1) for the study and abatement of the water pollution problems of Escambia and Santa Rosa counties;
   (2) for the study and abatement of the dog fly;
   (3) for the study of Choctawhatchee Bay and related waters.
2. To establish a data bank at The University of West Florida relating to water pollution, dog fly, and estuarine studies and provide for information dissemination program.
3. To develop a unified interagency (local, state, and federal) and interstate effort to investigate and solve the above listed problems in a systematic fashion.

The first meeting of the council was held June 1969, with Governor Kirk in attendance. Chairman Crosby moved quickly to establish council committees and to organize task forces (a table of organization appears in Figure 1). It should be stressed that this organization was considerably more than a hastily organized group of scientists, politicians, and community leaders gathering together for a common cause: estuarine preservation and coastal zone management.[37]

Council meetings were open not only to the public but also to agency officials who attended and participated in meetings. Congressman R. L. F. Sikes expressed his support and in fact acted on the council's behalf in Washington, D.C.[38]

By August 15, 1969, the West Florida Natural Resources Council was ready to approve budgets totaling over $700,000 for the various task force operations, as follows:[39]

Escambia-Santa Rosa Pollution	$150,000
Choctawhatchee Bay	203,306
Dog Fly Control	356,670

Local citizens, however, were critical of the proposed allocations. It appeared to them that dog fly control and tourism were more important than "clean water." Although this reaction reflected accurately some local attitudes, the council was simply hearing and acknowledging proposed first-year costs. The question of where the money would come from was still to be examined.

The first task force to make a report of progress to the council was the Escambia-Santa Rosa Water Pollution Task Force which on October 8, 1969, reported to the eager citizenry that Escambia River and Bay were grossly polluted and that the major polluters were three local manufacturing industries and the local power generating plant.[40] This report was delivered to a standing-room-only council meeting and it was what the area citizens were anxious yet fearful to hear. Relatively clear answers to questions that the Pensacola News-Journal had asked previously and with increasing tempo were provided to the citizens that day. The report gave them a springboard for involvement.

At the same time that the council was establishing its credibility and achieving local praise for its efforts, unforeseen and intangible difficulties were beginning to take a form that would bring about the ultimate demise of this laudable attempt to establish approaches to coastal zone management. These forces are not unrelated:

1) *Lack of fiscal support.* Although the West Florida Natural Resources Council had been in operation over four months, it did not have a meaning-

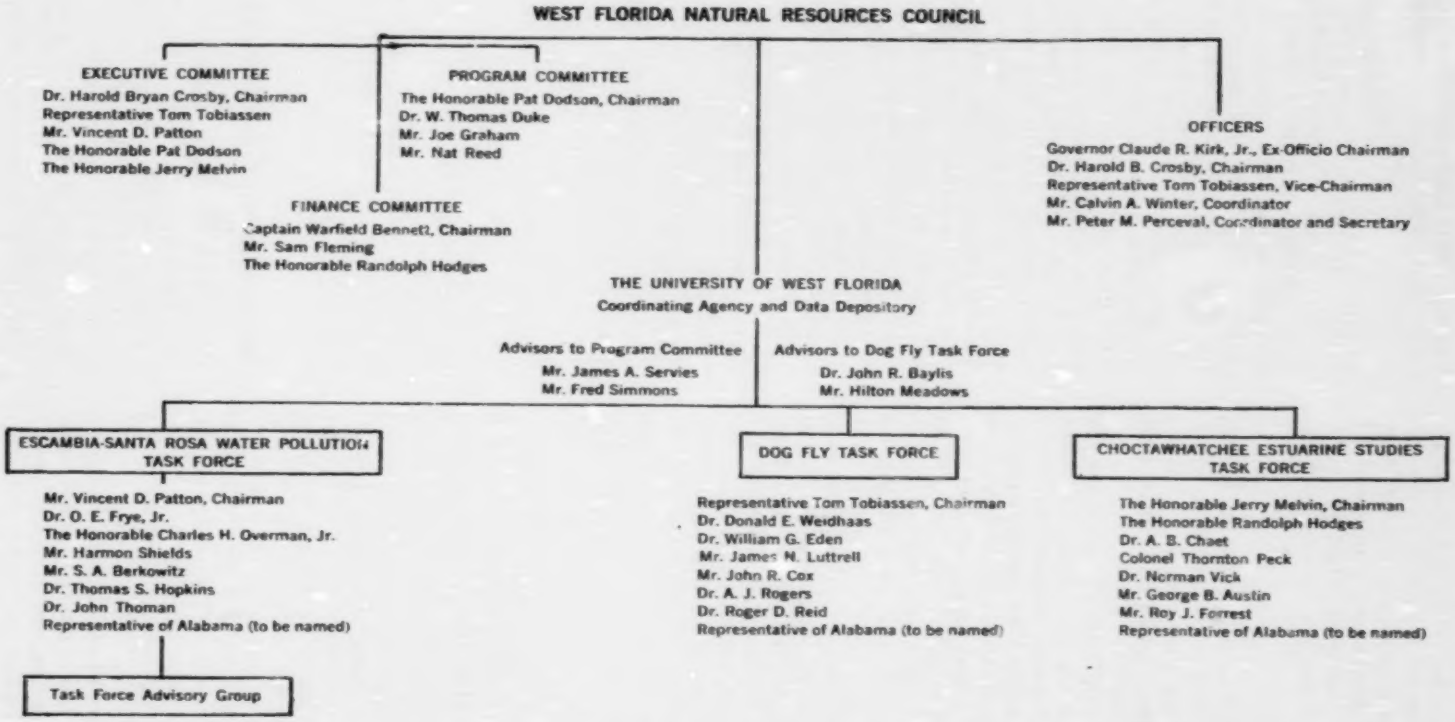
WEST FLORIDA NATURAL RESOURCES COUNCIL
EXECUTIVE COMMITTEE
Dr. Harold Bryan Crosby, Chairman
Representative Tom Tobiassen
Mr. Vincent D. Patton
The Honorable Pat Dodson
The Honorable Jerry Melvin
PROGRAM COMMITTEE
The Honorable Pat Dodson, Chairman
Dr. W. Thomas Duke
Mr. Joe Graham
Mr. Nat Reed
FINANCE COMMITTEE
Captain Warfield Bennett, Chairman
Mr. Sam Fleming
The Honorable Randolph Hodges
OFFICERS
Governor Claude R. Kirk, Jr., Ex-Officio Chairman
Dr. Harold B. Crosby, Chairman
Representative Tom Tobiassen, Vice-Chairman
Mr. Calvin A. Winter, Coordinator
Mr. Peter M. Perceval, Coordinator and Secretary
THE UNIVERSITY OF WEST FLORIDA
Coordinating Agency and Data Depository
Advisors to Program Committee
Mr. James A. Servies
Mr. Fred Simmons
Advisors to Dog Fly Task Force
Dr. John R. Baylis
Mr. Hilton Meadows
ESCAMBIA-SANTA ROSA WATER POLLUTION TASK FORCE
Mr. Vincent D. Patton, Chairman
Dr. O. E. Frye, Jr.
The Honorable Charles H. Overman, Jr.
Mr. Harmon Shields
Mr. S. A. Berkowitz
Dr. Thomas S. Hopkins
Dr. John Thoman
Representative of Alabama (to be named)
Task Force Advisory Group
DOG FLY TASK FORCE
Representative Tom Tobiassen, Chairman
Dr. Donald E. Weidhaas
Dr. William G. Eden
Mr. James N. Luttrell
Mr. John R. Cox
Dr. A. J. Rogers
Dr. Roger D. Reid
Representative of Alabama (to be named)
CHOCTAWHATCHEE ESTUARINE STUDIES TASK FORCE
The Honorable Jerry Melvin, Chairman
The Honorable Randolph Hodges
Dr. A. B. Chaet
Colonel Thornton Peck
Dr. Norman Vick
Mr. George B. Austin
Mr. Roy J. Forrest
Representative of Alabama (to be named)

FIGURE 1.—Organizational diagram for the West Florida Natural Resources Council (now defunct).

ful "bankroll" to support any of its task forces. In addition, its own administrative costs were growing.

2) *Governmental reorganization.* The State of Florida consolidated several agencies and clarified certain roles in environmental protection, which probably destroyed the previous vacuum in coastal zone responsibility.

The fiscal woes of the council increased as the new state agencies jockeyed for larger budgets and operating room. It became clear that the WFNRC and its concepts so strongly endorsed in June were taking a back seat by December 1969.

President Crosby provided new life for the council in May 1970, by appointing Dr. Joe A. Edmisten as director of the council and coordinator of Coastal Zone Studies.[41] Fiscal problems continued to plague the council and by July 1970, only about $43,000 of the needed $700,000 had been found and allocated. For the Escambia-Santa Rosa Water Pollution Task Force, $18,000 was provided by the Department of Pollution Control; $25,000 was provided for the Dog Fly project from other state funds. But in spite of this limited funding, citizen involvement continued and it was during this period that the Bream Fishermen Association (BFA) joined the "clean water" task force. At this time, the WFNRC was optimistic that more funds would be found.

The council met in August to hear a proposal for a "coastal zone inventory" and urged the Department of Natural Resources to adopt a uniform inventory plan.[42] This resulted in Dr. Edmisten urging Governor Kirk to declare the Escambia Bay a natural disaster area, "To become eligible for federal aid in the form of grants and loans designed to help fishermen and shrimpers of the area stay in business . . . until we are able to restore Escambia Bay to its original healthy state."[44] The council's executive committee explored this possibility in September 1970, with many citizen groups being represented. After considerable debate, it concluded that the area was not eligible for federal funds.[45] The council met again in October 1970, and learned that the newly formed Coastal Coordinating Council (CCC) operating out of the Department of Natural Resources was implementing a plan for a statewide uniform inventory of natural resources. The CCC would start its plan using Escambia and Santa Rosa Counties as a pilot area called "Escaros." This appears to have been the last real meeting of the council.[46]

In summary, the West Florida Natural Resources Council was born in a time of need and undoubtedly realized some major achievements in citizen involvement and estuarine preservation. It died slowly but steadily as other state agencies increased their activities and manpower resources in the panhandle region.

West Florida Regional Planning Council.—The West Florida Regional Planning Council (WFRPC) was created in 1964 under the authority of chapter 160 of the Florida Statutes. Starting as a one-city one-county agency, the planning council now serves three counties and many municipalities.[47]

In the area of estuarine preservation, the state has designated the WFRPC as the planning agency for "Development of Regional Impact in Escambia, Santa Rosa, and Okaloosa Counties." At the federal level it has similar designations, particularly in the area of water quality management where this policy interfaces with the Environmental Protection Agency in comprehensive planning. Although the WFRPC has a professional staff its operations are governed by a citizen board representing the cities and counties under the WFRPC umbrella.[47]

One of the major achievements of the regional planning council was the development of water quality management for Escambia and Santa Rosa counties. This plan was funded under Section 3c of the Federal Water Quality Act of 1965. The grant application was filed in 1972 and work began. The plan is oriented toward estuarine preservation and is cost effective. Its goal is to significantly reduce the amounts and richness of surface discharge into estuarine areas.[48,49]

In addition to the plan cited above, the regional planning council acted as a coordinating agency to develop a plan for the restoration of Bayou Texar, cited earlier. The council also works with projects in the three-county area involving prospective development—e.g., what impact a large multi-service shopping mall and its collective runoff will have on the estuarine receiving waters.

In summary, the WFRPC is a citizen board with responsibility for regional planning in a geographically complex estuarine area. Its professional staff and citizen board are called upon to make far-reaching decisions.

Governmental Advisory Groups

County Commissioners' Pollution Advisory Committee.—In the fall of 1970, after another year of disastrous fish kills, citizen outrage, and editorial comment, the county commissioners of Escambia County followed a recommendation offered by Wayne E. Tisdale, regional engineer for health and rehabilitation services, and created an advisory committee.[50] The citizen select committee was chosen

to represent business and commerce, sport and commercial fishing, industry, agriculture, the legal profession, and education. Acting Commission Chairman Sam Armour, "charged the committee with its responsibility to seek solutions to the pollution problems in Escambia County and to advise the Board of County Commissioners accordingly . . ."[51] The committee, hereafter referred to as ACOP, began to meet weekly and many citizen manhours were invested. It heard presentations by regional engineers from two state agencies, the county environmental health director, and several concerned citizens who reviewed the environmental problems from their viewpoints. In addition, the committee mailed out three questions to selected citizens in the community for written responses. These questions were as follows:

> (1) "How to Stop the Present Pollution of Our Environment"—Please outline any constructive solutions you may have relative to the air and water pollution of Escambia County. Of particular value will be specific technical/legal recommendations that can be implemented immediately by Escambia County.
>
> (2) "How to Prevent the Pollution of Our Environment in the Future"—Please outline any constructive solutions you may have relative to preventing pollution in the future. Recommendations relative to air and water quality standards for new industries, expansion of County and City sanitation facilities, etc., will be of value.
>
> (3) "How to Restore the Damage Done by Past Pollution Practices"—Past and present pollution practices have seriously damaged many of our areas. These areas must be restored to some reasonable resemblance of their original quality. Recommendations for their restoration (clearing the bottom, restoring fish and aquatic life, etc.) are requested. In addition, your ideas on how to fairly distribute the cost of such restoration would be appreciated.

The committee's purpose was to get as comprehensive a response as possible so that meaningful recommendations could be made to the county commissioners. In addition, the committee established several citizen subcommittees. For example, a "Solid Waste Disposal" subcommittee was set the task of studying how the county landfill was contributing to the pollution of Perdido Bay.

The Pollution Advisory Committee was very forthright and set to its task with considerable zeal. For example, in its first 30 days, it developed a series of thoughtful, action-oriented recommendations dealing with the estuarine environment.[52] Although recommendations were rarely adopted by the county commission, the thrust of the committee created beneficial side effects and interest on the part of the commissioners themselves. For example, the commissioners held hearings concerning the establishment of nutrients and thermal discharge limits. This procedure allowed industry representatives to present their views with citizens in attendance.[53]

Although the advisory committee was frustrated in attempts to establish regulations for local industry, it was very successful in negotiating safe practice regulations for the Humble Oil and Refining Company which was requesting permission to install pipelines in the delta region of Escambia and Perdido Bays. Indeed, the attentiveness and cooperation given by the Humble Oil Company in meeting with citizen committees might serve as a model for other agencies seeking permission to carry out potentially deleterious projects in the estuarine area.[54]

The advisory committee pursued its regulatory interests in 1971, working closely with the Department of Pollution Control and developed a model local program which was unfortunately tabled.[55,56] On the plus side, however, was the opportunity for citizens to interact with state officials in a constructive way to bring about estuarine preservation.

In 1972 the Escambia County Commission was reorganized, and the new chairman created a new citizens organization called VOICE (Voices of Interested Citizens of Escambia). Although the Advisory Committee on Pollution (ACOP) was allowed to continue, it became apparent that it would be akin to a forgotten stepchild. Nevertheless, the committee has continued to meet and act on matters referred to it by the commissioners. Ironically, the county commissioners reorganized again in 1974, and the new chairman has indicated that the services of VOICE will be discontinued. The fate of ACOP has not been announced.

In summary, the Citizen's Advisory Committee on Pollution matters in Escambia County was created in response to citizen concern over rampant environmental degradation in the county. The committee was very active in its initial year of operation, but as is so often the case, a citizens' committee is quite capable of recommending solutions which are beyond financial, legal, or political grasp of the local, state, or federal government agency to which it reports.

Technical Advisory Committee, West Florida Regional Planning Council, Water Quality Management Plan.—Without going into great detail concerning this activity, it should be noted that the Water Quality Management Plan cited earlier was developed through the guidance and approval of a committee containing not only local, state, and federal professionals but lay citizens as well. Serving on this committee were citizen advisors Clyde Richbourg of

the American Seafood Company, and Tony Raibl, representing the Bream Fishermen Association.

Regional, State, and Federal Hearings

Earlier, I referred briefly to hearings at the county level resulting from efforts of the County Commissioner's Advisory Group. State and federal agencies have held hearings also, and these hearings are a meaningful outlet for citizen concern and education. Enumeration of three such hearings follows.

Regional Planning Council Hearings.—The West Florida Regional Planning Council held a series of public hearings concerning the Water Quality Management Plan. Although these hearings were advertised in the newspaper and on TV, they were rather poorly attended. The final hearing in May 1974, attracted only 54 people, including participants.[49] This number is less than 0.1 percent of the city of Pensacola's population, much less of the two-county area represented. It would appear that with pressures of the economic recession we are in, citizens are turning their backs on interests and concerns of four years ago. This probably will be evident in federal hearing attendance data as well.

State Agency Hearings.—The scenario for hearings concerning Escambia Bay begins earlier than 1969. However, the first major hearing which drew a sizeable citizen turnout was on May 21, 1969. At this time, the Florida Air and Water Pollution Control Commission with Governor Claude Kirk, Jr., in attendance held a hearing entitled "Investigation of Water Quality in Escambia River, Escambia Bay, Pensacola Bay, and Perdido." Presentations were made by four state agencies, the city of Pensacola, and the state of Alabama. Several persons asked to be heard and were granted appearances. These included the chairman of the Pensacola Anti-Pollution League and a representative of the Florida Wildlife Federation. The hearing, well-attended for the time, drew 150 persons.[57,58]

Federal Agency Hearings.—Beginning in January 1970, the Federal Water Pollution Control Administration, which held hearings on Escambia Bay on January 21 and 22, began a series of enforcement conference hearings concerning water quality in Escambia Bay and Perdido Bays.[2,6] Although the 1970 hearing on Escambia Bay attracted over 290 participants, the second session on February 23, 24, 1971, attracted less than half the previous number and the third session on January 24–26, 1972, showed a further decline in audience participation. This decline in attendance is regrettable, for such hearings are vital to estuarine preservation. Federal agencies should be encouraged to report in open hearings what they are doing about their agency-stated goals, and citizens need an opportunity to tell federal and state officials what concerns them. Even though some citizen concerns may be ephemeral on the one hand, and state and federal action or processes slow on the other, constant and better communication is imperative. In this regard, it is unfortunate that the Escambia-Perdido Bay conferences have not been reconvened each year and that many citizens believe that such enforcement conferences have been unsuccessful in bringing about any real change in pollutants and water quality.

Miscellaneous Clubs and Other Organizations

During the period of greater citizen concern over Escambia Bay, there was a great deal of organizational interest from the standpoint of group education. Additionally, many of these groups or organizations actually mobilized in force to attend hearings, workshops, or write letters. Not wishing to ignore or play down the role of any citizens' group, I want to acknowledge the contributions of those organizations that I can recall which were interested and active:

Sierra Club of Pensacola
National Wildlife Federation, local chapter
Frances M. Weston Chapter, Audubon Society
Save-Our-Beach Committee
Florida Federation of Garden Clubs
League of Women Voters
Pensacola Womens Club
Junior League of Pensacola
Pensacola Junior Chamber of Commerce
Rotary of Pensacola
Kiwanis of Pensacola
Greater Pensacola Chamber of Commerce
Choctawhatchee League for Environmental Action Now (CLEAN)
Gamefish Protection Association (Okaloosa-Walton County)

All of these organizations and perhaps others as well were concerned enough to invite me, enforcement officials from state agencies, or industry spokesmen to meet with their groups so that they could become acquainted with estuarine problems. Of the above groups, the Sierra Club of Pensacola is currently the most active in preservation.

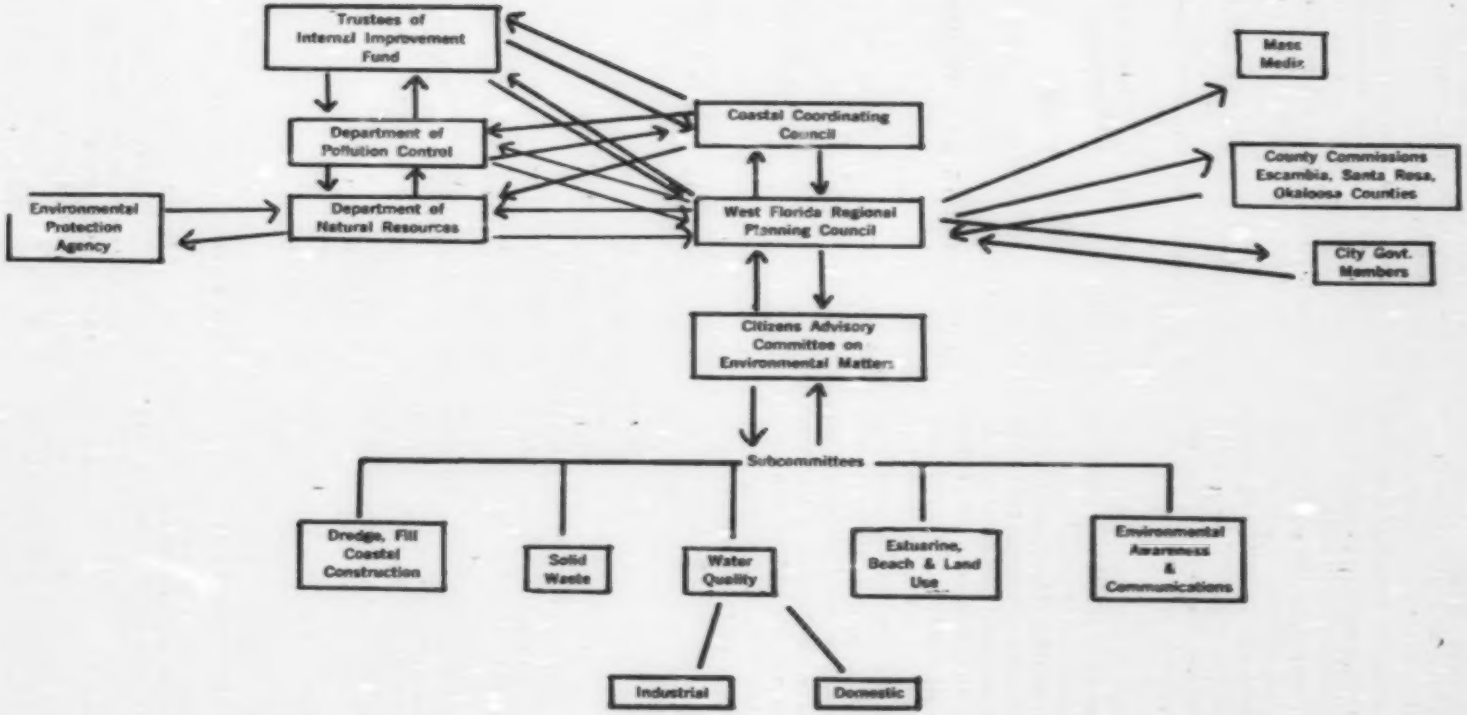

FIGURE 2.—Flow diagram showing how the West Florida Regional Planning Council could consolidate citizen involvement.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. This paper has discussed the background and context of citizen awareness and involvement in estuarine preservation in northwest Florida.

B. Vehicles and mechanisms for citizen involvement are through (a) sportsmens' organizations, (b) homeowners' organizations, (c) planning councils, (d) local, state, or federal advisory groups, and (e) attendance at local, state, and federal hearings. Other routes of involvement include civic clubs, conservation groups, and semi-professional societies.

C. In all cases, there are certain pragmatic, legal, fiscal, or economic issues that influence the success of the concerned individual or organization.

D. Considering these realities, it is proposed that the best avenue for estuarine preservation in the geographic locale of northwest Florida would be through the West Florida Regional Planning Council (Figure 2 shows schematically how the Regional Planning Council concept would be applied). It should be noted that if the WFRPC assumed this added responsibility, additional staffing would be a necessity. On the other hand, use of this existing agency would seem to be the most cost effective and would be consistent with its legislatively mandated role. Furthermore, it is the agency most closely in tune with the Coastal Coordinating Council which would be responsible for the implementation of Coastal Zone Management in Florida.

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THE ROLE OF THE PUBLIC IN TEXAS ESTUARY PROTECTION

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ABSTRACT

The projected superport inside the South Texas bay system at Harbor Island, near Corpus Christi, stirred public indignation to a high level. Here is the way the people of South Texas reacted—and the methods they used to make their voices heard.

INTRODUCTION

The Texas coast is, historically, the most unappreciated part of Texas.

Texas is land, lots of land—267,339 square miles which form a highly individualistic link between the Old South and the Rockies and between the Great Plains of the Midwest and the subtropics of the U.S.-Mexico border. It is more than 800 straight-line miles from the northwest corner of the Texas panhandle to the southernmost curl of the Rio Grande below Brownsville. The east-west distance from the broadest bend of the Sabine River to the pointed tip above El Paso is almost as great.

If all states were as big as Texas, there would be only 13 states. There is room enough in Texas for 220 states the size of Rhode Island or six states the size of New York. The largest of Texas' 254 counties is almost as big as New Jersey. If a state were molded to the same size and shape as Texas and placed directly east of Texas, it would reach 35 miles into the Atlantic Ocean beyond St. Augustine, Fla. A state cut from the Texas pattern and located directly west of Texas would extend 160 miles into the Pacific Ocean beyond San Diego, Calif. Texas above itself would come within 50 miles of the Canadian border. Beaumont, some 25 miles west of the Louisiana border, is nearer to Sarasota, Fla., than it is to El Paso. And El Paso is nearer to Los Angeles, Calif., than it is to Beaumont. Dalhart, at the top of the Texas panhandle, is closer to Pocatello, Idaho, and Billings, Mont., than to Brownsville.

Texas is crops and cattle and mineral wealth—and all the economic, manufacturing, industrial, and metropolitan muscle such broad-based elements of prosperity can be expected to produce. For 38 consecutive years Texas has been No. 1 among the states in mineral output. It is first in petroleum production and first in petroleum refining. More than one-fourth (26.5 percent) of all crude oil refining in the United States is in Texas. Texas refines more crude oil than the total amount refined in California and Louisiana, the second and third ranking states. More than 35 percent of the proved natural gas reserves in the United States are in Texas. Both agriculture and ranching are multi-billion-dollar annual businesses. Texas usually leads all states in producing cattle, sheep, lambs, goats, cotton, and grain sorghums. It competes with Louisiana for first position in rice growing.

Today, the mythical concept of Texas and Texans remains rooted to the wide open spaces despite the fact that Texas has become one of the most urbanized of all states, powered not by rugged individualism but by big-dollar economics and a prosperity-nurtured growth mania. In 1940—barely a generation ago—Texas had a population of 6,414,824 and was predominantly rural. By 1970, the population had grown to 11,749,100, and four of every five Texans (79.7 percent) lived in urban areas. There are 24 standard metropolitan areas in Texas—approximately 10 percent of the United States' total. There are two Texas metropolitan areas among the top 20 in the United States and 10 Texas cities have populations of 100,000 or more. Six metropolitan areas are on the Texas coastal plain, including three cities with 100,000-plus population.

In the 1920s, Houston advertised itself as the place "where 17 railways meet the sea." The slogan was right on target. Galveston, with its island location and natural harbor, had dominated shipping and commerce on the upper Texas coast for decades. In 1914, Houston was handed its chance to emerge commercially when a ship channel was dredged from the Gulf of Mexico inward across Galveston Bay and up Buffalo Bayou. Galveston had the better location but Houston had the better connections with inland points. The ship channel, it turned out,

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compounded the Houston growth impact by providing a settling strip for industries with a need for deepwater dockage and plant space.

The ecological atrocities, both along coastlines and across inland expanses, can be traced historically to the frontier concept that mankind and the environment are natural adversaries. The concept was an implied part of the manifest destiny credo that the land was there to be conquered and used and not necessarily understood. The shaky status of civilization on the front fringe of the advance across the North American continent gave impetus to this fundamental concept. If the inlands or the shoreline were respected, the degree of respect was measured by the degree of hazard imposed by the environment and not by the environment's intrinsic worth. It was only when mankind achieved a stranglehold on the environment and began converting conquest to excesses that the need to live in harmony with environmental resources came into focus.

Texas, rich in land and rich in both surface and subsurface resources, has grown by the frontier ethic of environmental conquest and has prospered handsomely. Houston has raised itself from its humble beginning as a shaky real estate promotion with a political hue to become one of the great cities of the world. Currently, Houston is the sixth largest city in the United States. By the start of the 21st century, just 25 years away, it easily could rank second only to New York. Already its position as one of the nation's four great anchor cities—New York in the east, Los Angeles on the west coast, Chicago in the north-center position, and Houston in the south-center—is assured. Nearly 400 corporations now make their headquarters in Houston and Buffalo Bayou is as busy as Main Street as ocean-going tankers and cargo vessels move to and from the docks of industrial installations crowded along its banks all the way to open water. Channel dockage space is so much in demand that branch channels are being shaped into the mainland to meet the requirements of still greater industrial development.

Houston is not the sum of it all, but the Houston growth saga has been an inspiring certification of the conquest concept for other communities along the Texas coast. Deepwater channels invariably attract industry and, at least during the free-wheeling fifties, engendered dreams of million-plus populations. Corpus Christi, reached by a deepwater channel in the late 1920s, bounced from 16th to 6th place among Texas cities between 1940 and 1950. Jefferson County, with upstream deepwater at Port Arthur and Beaumont, rose into the top half-dozen Texas counties in population by 1960. Brazoria County, with deepwater at Freeport, has more than quadrupled its population since 1940. The deepwater urge so possessed Brownsville that a channel was fashioned across a tidal prairie for a distance of nearly 20 miles, creating the illusion that ships, somehow, were crossing unbroken grazing land. Point Comfort, in Calhoun County, likewise became a deepwater port, and Galveston County, without space for industrial expansion on Galveston Island, settled for industrialization, with deepwater access, on the nearby mainland at Texas City.

The Texas coastline, by its dimensions and construction, accommodates economic and urban exploitation. It is a long coastline—a great arc reaching 367 miles from the Sabine River on the Louisiana border to the United States-Mexico boundary at the mouth of the Rio Grande. The coastline meanders mightily, following the contours of countless bays sealed from the splash of the Gulf of Mexico by a chain of narrow islands and peninsulas. If the Texas coast is measured by every twist and turn of the shoreline, its length is 624 miles.

The Mississippi River and its tributaries form a gigantic funnel which drains the entire national heartland, diminishes the rivers of the Deep South, and furnishes a flow that dominates and shapes the Louisiana coast. Texas, for the most part, is outside the Mississippi basin and beyond its influence. Instead of being beholden to a single river system, the Texas coast is fed primarily by eight river systems, most of which empty into bay systems of some complexity. The bay systems are, in one fashion or another, connected to the gulf by inlets between islands and peninsulas.

The Texas coastal islands and peninsulas actually are barrier bars—the work of waves which break on the continental shelf. The shelf reaches miles offshore and follows the contour of the mainland in a rather irregular fashion. Because the water above the shelf is relatively shallow, the waves scrape bottom, break, and cast their load of sand particles forward. The sand deposits build into bars which eventually grow into islands. Tidal inlets form where water breaks across the barrier bars in times of storm. Accumulations of marsh grass and silt between the bars and the mainland, where bays and lagoons run thin, turn some islands to peninsulas. There is evidence that some mainland ridges were prehistoric barrier islands which established total links with the existing land mass.

The estuarine settings of the Texas coast—where river flow and the wash of the gulf have achieved a delicate balance—have proved attractive to settlement and, as already indicated, handy for industrial and urban exploitation. The inlets from the gulf are easily pierced to create deepwater channels. The

rivers offer sources of freshwater attractively controlled by dam construction. Every stream is a potential channel and every river mouth has possibilities as a turning basin. From the vast surface resources of Texas come fodder for ocean-going freighters. Mineral resources provide the crude oil which makes possible coastal refining complexes, and natural gas provides power for plants which broaden the industrial productive base.

Not every community along the Texas coast can have deep water. There just are not enough inlets from the gulf to turn the deepwater dream into every town's reality. For those who must settle for less, there is the Intracoastal Canal, which cuts across protected waters and marshlands of the landlocked bays and lagoons all the way up the Texas coast. The Intracoastal Canal continues across the southern swamps of Louisiana to the Mississippi River and coastal points to the east. Harlingen and Victoria, both on the coastal plain but a few miles removed from coastal bays, have settled for barge canals. Raymondville, likewise removed, has built Port Mansfield on the shore of Texas' southernmost lagoon and has engineered a barge channel through the center of Padre Island to the gulf. Even Dallas, some 200 miles removed from the gulf, dreams of a coastal connection by turning the Trinity River into an elongated barge canal.

The Texas shrimp and fish business is a multimillion-dollar enterprise, but so great is the industrial overshadow that commercial fishing hardly is visible. Tourism is a late arrival, primarily because the economy already had plenty to go on. Yet despite industrial overkill, municipal malfeasance, official neglect, and public indifference, Texas' estuarine resources still are sufficiently substantial to fight for—and people by the thousands are becoming aware of that fact.

THE PUBLIC STEPS IN

Houston, as a city, is a shining example of urban success. The way Houston has treated its access to the Texas coast is less than exemplary. It is frightening.

Buffalo Bayou originates west of Houston, passes through the city, widens into a turning basin and channel, then winds its way eastward to the northern niche of Galveston Bay. The bay is one of the largest estuarine areas along the Texas coast, gathering, in addition, the waters of the San Jacinto and Trinity rivers.

Buffalo Bayou must be the filthiest stream in the world. Years ago an investigator for Harris County pronounced the bayou's flow to be 80 percent sewage. In 1967, Dr. Joseph L. Melnick of the Baylor University Medical School examined the bayou's water in downtown Houston—long before it reached the ship channel area—and found what he calculated to be enough viruses to infect 77 million persons per hour. "It's just plain sewer water," Dr. Melnick, a virology expert, said. "You shouldn't bathe in this water. You shouldn't even get it on your skin. You shouldn't have anything to do with it." Four years later—in June 1971—two of Houston's sewage plants were discharging 103 million gallons of unchlorinated waste into Buffalo Bayou each day.

Galveston Bay, of course, is paying the price of such wanton pollution. A large part of the estuary has been closed to shellfish harvesting because of the bacterial pollution from raw and unchlorinated sewage. Fish kills attributable to both urban and industrial pollution are common. Fish deformities are becoming more apparent. And the bay—the prime recreation center for Houstonians for many years—now is shunned as unfit for swimming, fishing, and other water pleasures. The bayshore, once lined with piers and boat stalls, has little more than a scattering of battered posts sticking from its discolored waters as reminders of happier days.

The prospects of bringing Galveston Bay back to a healthy condition are, at best, poor. The Trinity River canal project still hangs around, threatening the bay's most significant source of freshwater and hazarding, by inundation, prime estuarine marshlands. Thermal pollution—the tampering with water temperature in the bay—is being posed by electric generating plants. A proposed dyke-and-levee system threatens tidal flow from the gulf. But while the prospects of making Galveston Bay a recoverable resource fade, there is grassroots reaction in Houston, at Wallisville, and, especially significantly, at Corpus Christi.

Before it reaches sewage stations and the long chain of industrial waste outlets, Buffalo Bayou meanders through ritzy River Oaks, a residential area ranking with the finest anywhere in the United States.

The benign little bayou forms part of the setting—and its value in its natural state is recognized by wealthy homeowners as well as public-interest conservationists. In 1971, a plan was developed to straighten the bayou channel in the name of flood control. Thus was born The Bayou Preservation Association, an alliance of property owners and environmentalists who mounted a full-scale opposition program and went public. The flood control project was stopped, and, perhaps most significant of all, the Association gathered the support of the Harris

County Soil and Water Conservation District, the Flood and Drainage Committee of the Houston Chamber of Commerce, and the Houston Builders Association in seeking an officially acceptable comprehensive plan for flood-plain management in the Houston area.

The achievement, in itself, was modest, and, for many of those involved, it was self-serving. But it was a forward step in coping with the Buffalo Bayou problem—a foot-in-the-door move toward bigger things in the somewhat belated effort to attach value to the quality of a clean stream and a healthy estuary.

An attempt to stop construction and operation of the Wallisville Dam on the lower reaches of the Trinity River still hangs in legal limbo, but the mere fact that such a step was taken and was treated with credence in the courts is noteworthy.

The Wallisville project, which would dam the Trinity at a point where the river flows into that part of Galveston Bay known as Trinity Bay, would create a shallow lake over nearly 13,000 acres of marine nursery grounds. While it would stop the movement of salt water up the Trinity channel, it also would adversely affect the flow of freshwater into the bay.

The suit was brought by two individuals joined by various environmental groups, including the Houston Sportsmen's Club, the Texas Shrimp Association, the Environmental Protection Fund, the Houston Audubon Society, and both the national organization and the Houston Chapter of the Sierra Club. The suit is based on the premise that the Wallisville project is related, in its implications, to the channelization of the Trinity to Dallas—and that the environmental implications of such wholesale tampering with one of Texas' more significant streams have not been fully assessed. Win or lose, the Wallisville Dam foes are sure to give heart to others who would undertake other fights to halt assaults on Texas estuaries. They already have—as is evidenced in the pitched battle to stop the construction of a superport at Harbor Island, a marshy triangle of land inside the Texas island chain near Corpus Christi.

THE HARBOR ISLAND BATTLE

Harbor Isand is located just inside San Jose and Mustang islands. The waters which move through Aransas Pass, the inlet from the gulf between San Jose and Mustang, break against the eastern point of Harbor Island and surge along its sides and through a shallow channel in its center into a system of 11 bays that form the shoreline of the southern half of the Texas coast.

The gulf waters surging along the south side of Harbor Island move into Corpus Christi Bay, then into Nueces Bay, Laguna Madre, and Baffin Bay. The Nueces River system and a variety of smaller streams match the flow from the mainland. The seawater flow through Harbor Island nourishes Redfish Bay. Along Harbor Island's north side, the Lydia Ann Channel carries water from the gulf to Aransas, Copano, Port, St. Charles, San Antonio, and Hynes bays. The estuarine balance in the latter bays is maintained by the flow of the Guadalupe-San Antonio river system and the lesser Aransas and Mission rivers.

There already is a deepwater channel from the gulf through the San Jose-Mustang inlet. It courses south of Harbor Island across Corpus Christi Bay to the Corpus Christi metropolitan area. A fork of the channel—also deep enough to accommodate ocean-going vessels—attaches itself to the industrialized north shore of Corpus Christi Bay for a short distance.

The Harbor Island superport would provide dockage for medium-sized VLCCs—the so-called supertankers designed to carry million-barrel crude oil cargoes from distant ports. The superport plan is sponsored by the Nueces County Navigation District No. 1 and enjoys the support of most of the community's powerful industrial interests and certain vocal segments of the Corpus Christi business establishment. To construct such a facility would necessitate substantial widening of the San Jose-Mustang inlet, fashioning of a super turning basin where inflow waters make their three-way separation into the various bays, cutting of berthing space into Harbor Island, relocating of the shallow channel through Harbor Island to Redfish Bay, and dredging of the inlet, turning basin area, and berthing area to a water depth of more than 72 feet.

The proposed superport provoked what The Corpus Christi Caller described as "The Battle of Harbor Island, 1973 Style." The Coastal Bend Conservation Association assumed the lead role, supported by the San Antonio-based Committee to Save Our Texas Beaches and Bays. The opposition began forming in mid-August, 1973. The showdown dates were September 19–20—the appointed time for a public hearing before the U.S. Engineers in Corpus Christi.

The results of the hearing were not conclusive, of course. But the month-long effort by conservationists to muster and consolidate public support added a blueprint for future action by environmentalists.

The superport opponents began with a sound basis for opposition. There was a plausible alternative: the monobuoy. A monobuoy system would provide for the unloading of the big tankers far out in the

gulf through the use of hoses attached at the water surface to floating buoys and at the gulf floor to underground pipelines leading to shore. Monobuoys would eliminate the need for an onshore port—and they could be expected to be more than theoretically effective. More than 100 monobuoy systems are in use around the world. Some have been in use since 1959.

Furthermore, it turned out, the monobuoy system had strong support and the dredging approach had outspoken critics in official circles. No less an authority than the U.S. Corps of Engineers—the agency holding the hearing—had expressed itself this way in a June 1973, report entitled "Report on Gulf Coast Deepwater Port Facilities in Texas, Louisiana, Mississippi, Alabama, and Florida': Of the three facility systems investigated—dredged channels, artificial islands, and monobuoys—the monobuoy system is the most economically and environmentally feasible."

Speaking specifically of the Texas Coastal Bend—the area centered around Harbor Island—the Corps added: "This zone supports active commercial and sport fisheries and represents a significant recreational region whose utility could be diminished by a deep port development in the area . . ."

A report entitled "Environmental Aspects of a Supertanker Port on the Texas Gulf Coast," published in December 1972, by Texas A & M University, contained this statement:

> In addition to the first cost aspects of channel deepening, other considerations which, when taken in toto, appear to rule out this approach as an alternative to the offshore port, include such things as annual maintenance costs and environmental impacts other than those associated with disposal of dredge spoil . . .

The U.S. Army Engineer Institute for Water Resources had retained Robert R. Nathan Associates, Inc., of Washington D.C., to prepare a report entitled "U.S. Deepwater Port Study" in August 1972. The report stated:

> Dredging and spoil disposal for deepwater ports, if resorted to on a massive and extensive scale, could create environmental problems almost equal to those of petroleum spills . . . However, for the most part, offshore facilities requiring limited or no dredging offer an economic, and environmentally less destructive alternative for crude petroleum imports . . .

The Texas Environmental Coalition focused directly on the proposed Harbor Island project with "A Statement Concerning Deepwater Port Location in the Corpus Christi, Texas, Area." The statement was drawn by Espey, Huston, and Associates of Austin, Tex., and contained this comment: "Establishment of a major oil depot with very large tankers coming into the Aransas Pass area will increase the oil pollution because some leakage, spillage, and escape is unavoidable . . ."

One of the strongest statements was found in "Offshore Terminal Systems Concepts," prepared by Soros Associates, Inc., of New York for the U.S. Department of Commerce Maritime Administration. The statement read:

> The traditional coastal port consists of entrance channels, anchorage areas, turning basins, and shoreside terminal berths . . . Many existing port structures would be undermined by further dredging. As bulk carrier depth requirements reach 60 to 100 feet, the practical limitations of the traditional port will have long been exceeded for practically all the existing primary bulk cargo ports, particularly on the Atlantic and Gulf coasts. The problems of turning and handling these large vessels within the traditional port confines will become dangerous even if dredged channels and basins could otherwise handle the deep drafts. Dredging beyond 50 feet in depth would be very difficult to justify both economically and environmentally.

The office of the Governor of Texas provided two general comments in "Texas Coastal Resources Management Program," a comprehensive report to Interagency Council on Natural Resources and the Environment. The comments:

> Bays and estuarine areas are irreplaceable resources essential to more than 70 percent of all marine organisms . . .
>
> . . . it is recommended that the State of Texas and its citizens . . . prohibit the sale or lease of State-owned wetlands for development except where essential to fulfill some definite human need and where no feasible alternative exists.

Thus armed with significant opinion, the Harbor Island superport opponents put their position to a public test. On Labor Day weekend, circulars entitled "Save Our Beaches, Save Our Bays" were passed out to motorists pulled to a stop on Harbor Island to await ferry movement to the Mustang Island community of Port Aransas. The circulars explained that a plan was afoot to build a superport on Harbor Island, then added:

> A superport on Harbor Island would require a channel almost three times as wide and nearly twice as deep as the present inlet from the Gulf of Mexico.
>
> The cost would be enormous. The flood danger from tidal surges, particularly during hurricanes, would constitute a tremendous risk to lives and property. Uncontrolled oil spills could blacken a half-dozen bays, ruin our island beaches, do immeasurable damage to bird and marine life, and destroy a multi-million-dollar tourist and recreation area.

> Don't let anybody fool you—there is no way to control a tidal wave and no fool-proof way to stop the spread of an oil spill.
>
> And don't let anybody tell you that a superport inside the Texas island chain is necessary to support the Texas economy or to provide jobs. It isn't necessary. The U.S. Engineers have made analyses which show that an offshore terminal in the Gulf of Mexico would cost less and accomplish the same purpose.

The message urged anyone interested in stopping the Harbor Island superport project to sign a coupon on the bottom of each circular. The response was tremendous. By the end of the 3-day holiday period, some 4,000 persons had read, signed, and returned the circulars. More than 1,500 other signatures were gathered, mainly in Corpus Christi, prior to the September 19–20 hearing.

A major newspaper advertising campaign was mounted. A dramatic three-color, two-page display featuring a map showing the proposed Harbor Island superport location and projecting the possible consequences of a major oil spill in the port area was the starter. The advertisement was captioned: "Are You Willing to Pay This Price for a Superport on Harbor Island?" The price, of course, was the possible saturation of the bay and estuary areas with crude oil.

The authoritative quotations cited above were put together in a full-page blockbuster with this caption: "Before You Let Anybody Talk You Into Believing the Harbor Island Superport Would Be Good for Corpus Christi and the Texas Coastal Bend, Read These Findings." The advertisement, like the circulars, contained a coupon for opposition signatures.

The next advertisement made it clear that there was an alternative to the Harbor Island superport. The heading stated:

> **Can Corpus Christi Have**
> **The Benefits of a Superport**
> **Without Jeopardizing Our**
> **Beaches and Bays?**
>
> **It Certainly Can—If**
> **The Port Is Built in the Gulf**
> **Instead of on Harbor Island.**

The pro-monobuoy statements by the U.S. Engineers were prominently displayed.

As the hearing date neared, 10 reasons why the Harbor Island superport should be opposed were offered:

1. The Harbor Island Superport Plan Already Is Obsolete. A superport inside our bay system at Harbor Island, as proposed, would accommodate only medium-sized supertankers. Ships almost twice that large already are under construction and still larger vessels are being planned.

2. The Harbor Island Superport Limits Our Economic Benefits. If the large supertankers can't dock, they can't unload. If they can't unload, we lose economically. An offshore monobuoy system would make possible the discharging of crude oil from supertankers of all sizes.

3. The Harbor Island Superport Has an Unsigned Price Tag. If a 72-foot channel can be dredged, will we then be asked to dig it deeper for bigger ships? How will the channel be maintained? What will be the final cost? Who'll pay the bill? Why haven't these questions been answered?

4. Harbor Island Will Put Us Behind in the Superport Race. The construction of an inland superport is a mammoth, slow process. The Caller-Times of August 26, 1973 stated that officials have estimated results of the Harbor Island feasibility study "may not be available for up to three years." Construction then could require an even longer period of time, pushing the completion date to 1979 or later. If the Seadock monobuoy is put into operation up the Texas coast at Freeport in 1976, we could find our area three or more years behind in superport development.

5. Harbor Island Is a Throwback to Isolated Port Planning. The energy crisis is a national concern. So is the docking of supertankers. That's why coastwide port systems have been studied so carefully. The attempt to force isolated consideration of Harbor Island as a superport site is a step backward in port planning.

6. Harbor Island Endangers Our Entire Bay System. The inlet between St. Joseph and Mustang islands is the prime source of fresh seawater for our entire Coastal Bend bay system. The system includes San Antonio, Copano, St. Charles, Aransas, Redfish, Nueces, Corpus Christi, and a dozen smaller bays, plus the Laguna Madre. A superport directly inside the inlet would be a pollution nightmare. It's hard to imagine a more damaging superport site.

7. Imagine the Effects of a Harbor Island Oil Spill! An uncontrolled crude oil spill at a superport on Harbor Island could blacken our beaches and bays, endanger bird and marine life, and destroy a multi-million-dollar tourist and recreation area. Let no one fool you—there is no foolproof way to control a big oil spill.

8. The Harbor Island Superport Is a Multi-Danger Plan. The danger of ship collisions and groundings hangs over any plan to build an inland superport. An explosion could turn a supership loaded with crude oil or liquified gas into a gigantic floating

Are You Willing to Pay This Price
For the Harbor Island Superport?
Corpus Christi Bay
Gulf of Mexico
Save Our Beaches! Save Our Bays!

ILLUSTRATION 1

ILLUSTRATION 2

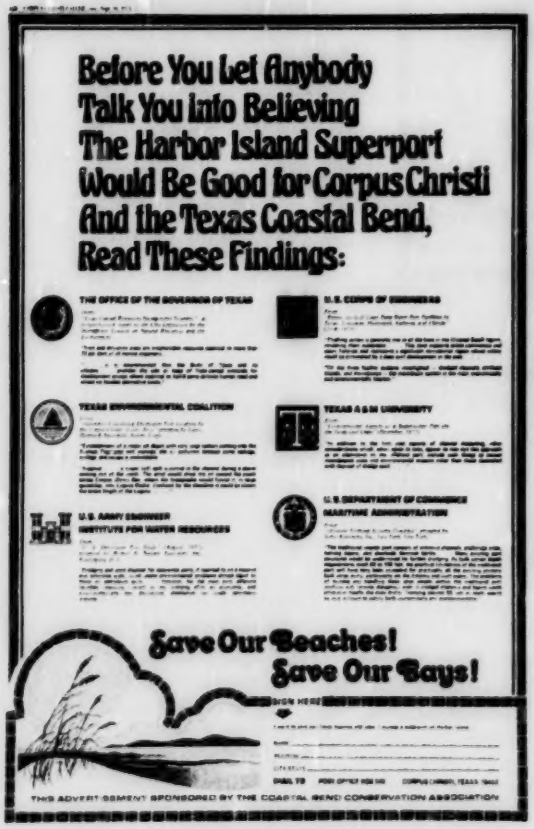
Before You Let Anybody
Talk You into Believing
The Harbor Island Superport
Would Be Good for Corpus Christi
And the Texas Coastal Bend,
Read These Findings:
THE OFFICE OF THE GOVERNOR OF TEXAS
U.S. CORPS OF ENGINEERS
TEXAS ENVIRONMENTAL COALITION
TEXAS A & M UNIVERSITY
U.S. ARMY ENGINEER
INSTITUTE FOR WATER RESOURCES
U.S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION
Save Our Beaches!
Save Our Bays!
THIS ADVERTISEMENT SPONSORED BY THE COASTAL BEND CONSERVATION ASSOCIATION

ILLUSTRATION 3

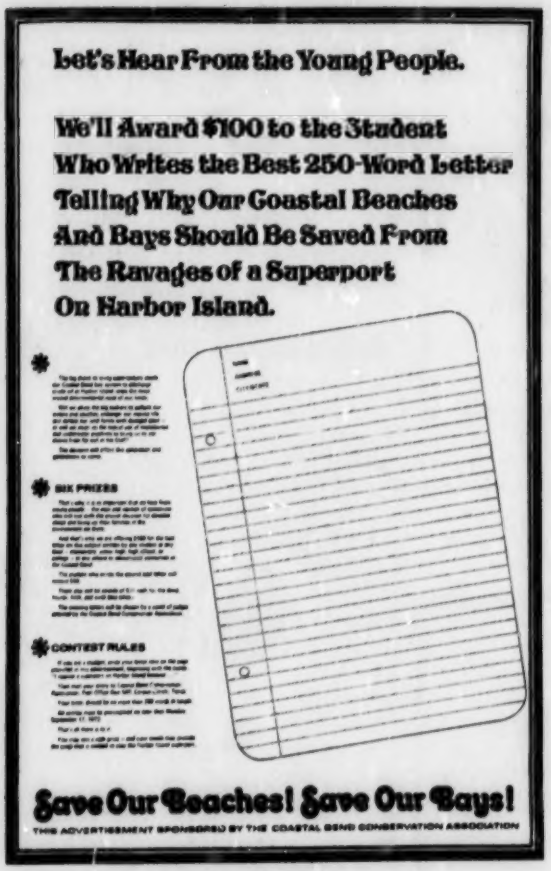
Let's Hear From the Young People.
We'll Award $100 to the Student
Who Writes the Best 250-Word Letter
Telling Why Our Coastal Beaches
And Bays Should Be Saved From
The Ravages of a Superport
On Harbor Island.
SIX PRIZES
CONTEST RULES
Save Our Beaches! Save Our Bays!
THIS ADVERTISEMENT SPONSORED BY THE COASTAL BEND CONSERVATION ASSOCIATION

ILLUSTRATION 4

bomb. There also is a real danger to life and property from tidal surges caused by channel widening and deepening to accommodate supertankers.

9. Harbor Island Will Blight Our Existing Economy. A superport inside our coastal islands will deface landforms with dredged spoil and pollute bay waters. It is bound to strike a solid blow to sport fishing, commercial fishing, bird life, tourism, and our own enjoyment of our environment. The cost in dollars will run into millions. The cost that can't be measured in dollars will be staggering.

10. All Major Studies Favor Offshore Superport Plans. The only thing new about superport planning is the high-pressure attempt to force the building of a superport on Harbor Island. Major studies conducted by and for federal and state agencies concerned with superport development favor offshore ports far out in the gulf.

The 10-point broadside was contained in a full-page newspaper advertisement with these instructions:

> **Here's What You Can Do To Stop the Harbor Island Superport—**
>
> **Go to the U.S. Engineers' hearing at 6:30 p.m. Thursday at Roy Miller High School Auditorium . . .**
>
> **Speak out at the hearing to save our beaches and bays by keeping the superport outside our Coastal Bend bay system.**

An advertisement—also displayed on a full-page scale—urged: "Let's Hear From the Young People." It offered, in the name of the Coastal Bend Conservation Association, a prize of $100 to the student writing the best 250-word letter "telling why our coastal beaches and bays should be saved from the ravages of a superport on Harbor Island." There was a second-place prize of $50 and four other prizes of $25 each. The contest was open to any student at any level—elementary, junior high, high school, or college—at any school or educational institution in the Corpus Christi area.

Each letter had to begin with the words: "I oppose a superport on Harbor Island because . . ." There were more than 100 responses.

As the hearing approached, The Corpus Christi Caller summarized the situation in a lengthy article published September 16. The article listed the pros and cons of the Harbor Island superport as follows:

PROS:

Economic boost.
Bring in new industry.
Decrease ship numbers (not tonnage).
Channel will stabilize bay system.
Help ease fuel crisis.

CONS:

Destroy fish, shrimp and crab nursery grounds.
Dredging and spoil disposal harm.
Oil spill danger.
Increased flood threat from hurricanes.
Expense of channel maintenance.
Demand on land, water, air resources from secondary development.

Port officials, the article stated, claim "the economical advantages of a landlocked inshore port situated inside the Aransas Pass Bar far offset any

possible ecological or environmental damage that might occur to the Corpus Christi Bay area."

But, the article added, "environmentalists maintain that construction of the port in estuarine areas will destroy valuable marine nursery grounds which are important for the preservation of gulf fisheries. They also argue that port development will inevitably lead to further industrialization that would decrease the quality of the area's environment."

The article, in its own right, pointed out that "more than 3,000 acres of land are estimated to be needed for facility construction. Much of this land is shallow and vegetated, functioning as nursery and feeding grounds for marine organisms and birds. Ninety-five percent of commercial fish species are said to be dependent on estuarine areas." It also cited the fact that Ernest Simmons, coastal fisheries supervisor for the Texas Parks and Wildlife Department, pointed out that construction of the deepwater port would immediately destroy many acres of prime spawning and nursery grounds for sea trout, redfish, flounder, blue crabs, and shrimp. "The deepwater port would thus affect adversely a multimillion dollar fishing industry. We would also lose feeding grounds for waterfowl and other birds," Simmons was quoted as saying.

Rudy Martinez, a biologist with Parks and Wildlife, and John G. Degani, field supervisor with the Division of River Basin Studies in the U.S. Bureau of Sports Fisheries and Wildlife, concurred with Simmons in print. Martinez was quoted as saying: "We are slowly losing our nursery grounds in this bay system as industry is coming in and people are building. The Harbor Island development would cut down on the amount of nursery grounds available for organisms." Most marine life spends some part of its life cycle in these areas, Martinez added.

Dr. Henry Hildebrand, of the Department of Biology at Texas A & I University-Kingsville, claimed publicly that the tremendous amount of spoil created by the dredging activities would keep the water turbid for months. "The fine clay sediments would create a turbidity off Port Aransas which would have serious impact on sports fishery. The fisherman will have to go much farther out to find the fish," the biologist said. Hildebrand said that besides the initial turbidity caused by the dredging, runoff from spoil disposal areas would have adverse consequences. "Draining from disposal areas of the colloidal clay sediments which would be dredged up could adversely affect the organisms in Redfish Bay and possibly cover up the grass-flats," he stated.

Hildebrand also commented that the 72-foot channel would profoundly affect the bay production of fish. The Aransas Pass Channel is a bottleneck for migrations in and out of the bays, he said, and thus the most sensitive area in the coastal system. "Little shrimp use certain clues to enter the estuaries from the gulf. Tidal and salinity changes resulting from a deeper channel would affect the migration pattern," he warned.

Dr. Charles Holmes of the Office of Marine Geology, U.S. Geological Survey, said: "The feeling among geologists is that the channel will fill in, but at a rate not known. The question should be investigated."

The hearing before the U.S. Corps of Engineers opened before a full house. The Miller High School Auditorium was packed—both the main level and the balcony. In the lobby, environmentalists passed out "Save Our Beaches, Save Our Bays" bumper stickers. Outside, a king-sized billboard trailer attached to an automobile carried an easily understood message. It stated: "Stop the Superport."

Edward C. Fritz of Dallas, chairman of the Texas Committee on Natural Resources and a leader in the Wallisville battle, testified: "The development plan for a multi-purpose deep draft inshore port near Port Aransas as presented by the Nueces County Navigation District is environmentally unsound. To construct the necessary deep draft access channels alone could seriously alter the balance of nature in the area. Any ecological modifications necessary to build and maintain a superport complex would have a serious and far reaching impact on the biosphere of an area. This particular plan threatens to wreak total havoc on the especially delicate and complex natural interrelationships in the Port Aransas region. Thus serious consideration should be given to the denial of a permit for this scheme. Indeed, serious consideration needs to be given to the question of whether or not any superport ought to be constructed at all in the Corpus area. One for Texas should be sufficient, and there are other areas with greater advantages to Texas and the nation."

Jake Powers, a petroleum consultant, told the gathering: "The Nueces County area is indeed fortunate in having a majority of its income derived from the petroleum industry . . . In fact many of us depend on petroleum in one facet or another as our basic income. We look forward to additional oil and the income it might bring. We do, however, feel like a superport would not benefit this area as well as an offshore terminal or monobuoy plan."

Yancey White—an attorney who is a graduate of the United States Merchant Marine Academy, a veteran of the United States Navy, and a former ship's officer in the United States Merchant Marine—pointed out that the secondary purpose of

the proposed Harbor Island superport was to load bulk carriers with grain for foreign shipment. "The hard evidence does not support the proposition that a bulk loading facility for grain at Harbor Island would be of any substantial benefit to the Port of Corpus Christi," White testified. "The reasons are simple and capable of factual support. The principal reason is that many of the countries purchasing our grain have severe draft limitations which restrict the size of the vessel that can enter the harbor for alongside discharge. To be specific, India, one of the primary purchasers of American grain, has severe draft limitations and cannot accept today vessels with 40-foot drafts which Corpus Christi is capable of loading. The maximum draft for which a vessel can enter a harbor in Venezuela is 34 feet. The maximum draft for alongside discharging in Mexico is approximately 30 . . . Stated in simple terms, it is futile to load a bulk carrier with grain to a 70-foot draft when the port of discharge can only accommodate a vessel of 30 feet. This is true because many, if not the majority, of the grain importing countries are underdeveloped nations and thus do not have adequate port facilities to receive large bulk carriers."

The chairman of the Corpus Christi Chamber of Commerce's Superport Committee was Edward H. Harte, publisher of The Corpus Christi Caller-Times. Later, in an editorial column, Harte gave his appraisal of what happened at the hearing at Miller High School. The Harbor Island superport project, Harte wrote, took a "terrible drubbing."

After the hearing, the environmentalists had the final words. In another double-page, three-color newspaper advertisement, they offered the public a sketch of a serene Harbor Island setting with this text:

Harbor Island . . . it's one of the Coastal Bend's great natural resources.

Around it flow the fresh seawaters which enter our island chain to feed our entire bay system from the Aransas National Wildlife Refuge at Austwell to the lower reaches of Laguna Madre. Its wetlands nurture our very existence, providing spawning beds for marine life and a nesting ground and natural habitat for countless species of birds. Along its sub-sea-level fringe is Texas' only mangrove swamp. Its delicate dunes have fashioned the contours of history.

There are some natural resources which must be sacrificed to that human on-rush known as progress.

This one must not be.

The unnecessary dredging of a deep-draft superport on Harbor Island for the unloading of crude oil from supertankers will deface the island itself, pollute our bays, endanger our commercial and sports fishing, and destroy our recreational and tourist attractions.

The public hearing held last week before the U.S. Corps of Engineers in Corpus Christi made it abundantly clear that the people of the Coastal Bend and those who share our concern about the well-being of the Texas shoreline want supertankers kept and unloaded where supertankers belong—in the deep waters of the gulf.

As one speaker pointed out, there is no last-gasp need for an inland superport on Harbor Island. To suggest that an inland superport is the only answer is to ignore the economy and efficiency of the offshore monobuoy unloading system.

Yes, the people spoke—not simply from the podium but by their presence. More than 700 persons attended the hearing. Nearly 6,000 others—enough to fill the Miller High School auditorium almost six times—sent their expressions in opposition to the superport in writing.

Harbor Island is a great natural resource—but it is even more.

It is the key to maintaining and improving the quality of life in the Coastal Bend.

It must not be sacrificed.

And it won't be.

The Harbor Island superport proposal has had rough seas ever since the September 1973, public hearing. In March 1974, Bechtel, Inc., a consulting engineering firm, put a $260 million price tag on the project. That is far more than the original estimates of less than $100 million. The $260 million cost, Bechtel pointed out, is based on a start of construction within 13 months. A start, as of this writing, is not in sight.

Perhaps the most significant factor for environmentalists is Bechtel's open reference to the project as Phase 1. What are the other phases? Where does the superport project lead? What is the full scope of potential estuarine destruction? In view of the Wallisville Dam litigation, these questions become especially relevant.

Untimely oil spills in the South Texas bay system related to the Mustang-San Jose inlet also have drawn attention to the hazards posed by the project. An oil spill closed the Port of Corpus Christi for two days. Almost a week was required to clear the channel of the 6,000-barrel spill. A smaller spill in San Antonio Bay, near the nesting grounds of the nearly-extinct whooping cranes, also attracted public attention.

Exxon, one of the industrial giants advocating the Harbor Island superport, came across its own tracks with a national magazine advertisement headed: "Offshore Oil Terminals. A safer, more economical way to get millions of barrels of oil from ship to shore to you."

An awareness of the value of Texas estuaries is growing. The importance of the role of the public in Texas estuary protection is undeniable. The blueprints have been drawn. The battle has been joined. And, for the first time, a genuine appreciation of the Texas coast seems near.

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THE ROLE OF CITIZEN ACTION GROUPS IN PROTECTING AND RESTORING WETLANDS IN CALIFORNIA

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ABSTRACT

The shocking destruction by man of California's wetland and coastal resources has occurred for more than a century, by competing uses for industrial, commercial, residential and recreational purposes. More than 80 percent of California's 21 million people live within one-half hour's drive of the coast. Pressures on resources in coastal areas is unbearable. This paper tells what citizen action groups have done in attempting to reverse these trends.

INTRODUCTION

Citizen action efforts in wetland and coastline protection in California, although of recent origin, are illustrative of some of the most dramatic and most productive results in the nation.

For more than a century following California's admission to the Union in 1850, it was common and accepted practice to misuse the coastline and to destroy the wetlands. Since 1900, 90 percent of the fertile and productive marshes, lagoons and sloughs in southern California have been diked, drained, polluted, filled, or dredged to make way for freeways, shopping centers, subdivisions, industries, condominiums, and marinas. Of the 381,000 acres of coastal wetlands existing in all of California 75 years ago, only 125,000 acres remain today.

Citizen action groups, tired of witnessing the slow but certain destruction of coastal shoreline waters and wetland habitat, decided to call a halt to such activities. Effective efforts of citizen groups in California have sometimes been on the local level and other times statewide. The methods used varied considerably.

Hopefully, the California illustrations cited will be beneficial to other citizen groups in the nationwide effort to save decreasing coastal wetlands from further destruction.

CARMEL RIVER BEACH AND UPLAND ARTICHOKE FIELDS

Saving threatened wetlands from destruction by fund raising for public purchase presents problems in that the amount of money needed is difficult to raise during the time available before the destructive action occurs, and should the purchase be successful who is to administer the wetland?

The saving of the Carmel River Beach, lagoon, and wildlife refuge from high density development was done by separate but interdependent citizen action groups—one concerned itself primarily with public education and fund raising, while the other carried on the political action.

Shortly after World War II the Carmel River Beach, with its unsurpassed view of Point Lobos, was up for grabs. Adjacent to the beach was a beautiful 27-acre lagoon, providing habitat for the brown pelican, blue heron, and many other species, some rare and endangered. Constant filling to make room for new homes in a nearby subdivision threatened the lagoon's very existence.

Determined to save this beach and wetland from development, Carmel citizens turned in 1950 to their Point Lobos League, a non-profit organization, whose purpose was to preserve natural, scenic and recreational areas for use and enjoyment by all of the people. Margaret Owings of the league solicited the aid of her friend, Newton B. Drury, chief of California's State Division of Beaches and Parks, who said of this effort, "No scenic and recreational resource in the United States is more sorely in need of preservation."[1] However, Drury, former director of National Park Service, was helpless under California law to purchase the Carmel River Beach and lagoon without local matching funds. With Drury's support, Francis Whitaker, the Point Lobos League's

[1] The Living Wilderness—Sumer, 1950, p. 17

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president (who was also Carmel's blacksmith), gathered artists, lawyers, doctors, journalists, retired military, and conservationists to his Forge in the Forest, where a campaign for vigorous fund raising was launched and a goal of $25,000 set. The league's efforts resulted in local artists donating 125 excellent paintings. Auctions and other money raisers produced $15,000 in donations to save the beach and lagoon. Of this effort, a well known journalist wrote,

> Contributions have been in the best conservation tradition, from small donors. These are the people from all over the United States—as well as little Carmel—who have known the sweeping curve of the beach with its yellow-white sand against the blue-green lagoon at the Carmel River mouth under the wild Santa Lucia Mountains![1]

Following the league's successful fund raising, the first breakthrough came when the state was able to acquire the 27-acre lagoon for a wildlife refuge. Pushed by the Point Lobos League, Monterey County made available to the state $25,000 in funds which it had earmarked for parks and beaches elsewhere in the county. The people of Carmel having done their part, the state then proceeded in 1954 to acquire an adjacent 80-acre beach and bluff, thus creating the Carmel River Beach and Wildlife Preserve.

To the east of the beach and wildlife refuge lies the 292-acre Odello artichoke fields that straddle Highway 1. For 47 years the Odello family had farmed these lands, but in 1971 they felt that the time had come to sell. Proposed was a $60 million development including 944 dwelling units, a 600-room hotel and a 300-acre spa to be located next to the wildlife refuge. Rezoning by the county would be required to make the project possible.

Worried about population increases, in that the proposed development would house more people than lived in Carmel, citizens again organized to save their environment. Traffic congestion, smog, tax burdens, damage to the state beach and wildlife refuge, and flooding of the Carmel River were all of great concern to the people. At first the controversy was fought solely on the political front. From the beginning there was widespread community feeling that the Odello family should be allowed to develop their lands as had others before them. Also, strong was support for purchase of the land for public open space preservation. To meet the developer's challenge, two organizations were formed. Each acted separately but of necessity depended upon one another if the land were to be saved. One organization known as the Carmel Area Coalition, together with other conservation groups, carried on the necessary political activity before the county planning commission and board of supervisors. The other organization, OLAF (Odello Land Acquisition Fund) was an IRS tax approved nonprofit corporation which confined its activities to fund raising. The landowners and developers were pushing for rapid approval of the plan and rezoning of the property. The coalition was strongly resisting this effort, thus hoping to buy time while OLAF was pursuing the herculean task of raising the money to purchase the land from the disinterested landowners at a then unknown price. Once the land was rezoned, the new inflated value caused by rezoning would put the price out of reach for public acquisition.

From February 1971 until the late spring of 1974 the battle to save the land continued. Prudential Life Insurance Company policy holders on the Monterey Peninsula and elsewhere were disturbed that their company was the financial backer of the plan. In May 1971 the company withdrew financial support and immediately thereafter the landowners indicated an interest in selling the westerly half of their property to OLAF, but only after rezoning was approved.

By June 1971 OLAF, backed by a $50,000 pledge from the city of Carmel, had raised $200,000 in cash and pledges and was trying to interest the State of California in acquiring the western half of the land to protect the state river beach and wildlife refuge. In July 1972 the planning commission, at a packed meeting, voted 6–2 to approve the development and in October, with growing support for public acquisition, the Monterey County Board of Supervisors reversed the planning commission in a 3–2 vote but without prejudice, meaning that the developers were free to re-apply.

The efforts of the coalition and conservation organizations were gaining increased support locally and throughout the state, and OLAF's fund raising efforts were truly amazing. Contributions flowed in from as far away as Hong Kong, Venezuela, and Washington, D.C. One social security recipient donated, and urged others who could afford it to contribute the small increase allowed in social security benefits! An 11-year-old boy on a street corner collected $105 in three hours time for OLAF. A wealthy woman gave a $30,000 Pebble Beach lot, and a druggist offered $.05 per bottle for the return of used pill bottles, receiving 4,080 pill bottles and sending a check for $108. The city of Carmel's pledge for $50,000 was later increased to $100,000.

High school students made door-to-door campaigns, and an ecumenical church service on the

[1] Robert E. Brunn, Carmel takes steps to save famed river beach. The Christian Science Monitor, June 13, 1950.

banks of the Carmel River gained more support; soon the national and east coast media with NBC, CBS, New York Times, National Observer, The Washington Post, and Halifax Nova Scotia Herald, as well as the National Geographic Magazine, all became interested in Carmel's trying to save its open space.

The State of California appraised the westerly 155 acres of the land at $1,750,000, and the Odellos agreed to accept this amount, but the state was only willing to provide one-half the cost.

Responding to the efforts of the coalition and OLAF, the county board of supervisors under the leadership of Willard Branson, its chairman, tried to form itself into a redevelopment agency to help obtain the matching funds, using tax increment bonds. Complicated political and legal problems caused the redevelopment idea to be abandoned. Then local assemblyman Bob Wood won legislative approval authorizing the purchase of the artichoke fields as an adjunct to the Carmel River State Beach. With the $100,000 pledge from the city of Carmel and the $250,000 raised by OLAF, and reduction by $100,000 in the landowners' selling price, the state furnished the balance and the sale was completed.

Thus, the westerly 155 acres of this land adjoining the wildlife refuge were forever preserved as a part of California's Carmel River Beach State Park and Wildlife Refuge, and efforts are still continuing to save the easterly one-half of the Odello land for open space.

Happily, the state leased the lands back to the Odellos, and green artichokes, interspersed with yellow mustard, still dominate the flatland next to the Carmel River Beach, lagoon and wildlife refuge across the bay from Point Lobos.

UPPER NEWPORT BAY

A 55-year struggle to preserve one of the last remaining wetlands in southern California culminated in a victory for conservationists when it was announced in mid-November of 1974 that the State Department of Fish and Game would supervise in Upper Newport Bay, Orange County, a 741-acre ecological preserve, the largest in the state.

Upper Newport Bay is located 26 miles south of Los Angeles and more than 80 million people, or one-half of the population of California, live within its 80-mile radius. The 3½ mile long Upper Bay, with its 1,000 acres of relatively undisturbed wetlands, provides a most important habitat for no less than five state and federally recognized species of endangered birds as well as important varieties of fish and plant life.

The saving of this important land and water from certain destruction of its natural resources is a lesson in community mobilization, effective public education, successful litigation, and determined citizen followthrough.

Prior to 1901 all tidelands in the Newport Bay area were held in trust by the State of California. In 1901 the state sold 273 acres of tidelands to James Irvine, the predecessor of the Irvine Company which is today the largest landowner in southern California. In 1919 the state granted to Orange County, in trust, other tidal and submerged lands for the development of a harbor in the Upper Bay.

As the result of litigation in 1920 between Orange County and the Irvine Company, Irvine was adjudged to be the owner of the lands above mean high tide, including three small islands whose ownership by Irvine blocked effective use of the bay for Orange County's proposed harbor development. In addition, precipitous bluffs owned by Irvine surrounded much of the bay, thus making access to the water difficult. Irvine wanted to develop its upland properties and obtain access to the bay, and Orange County desired to develop the harbor under its tidelands' grant. Consequently, a plan was evolved under which a land exchange would be made. It would permit Orange County to develop the harbor, a marine stadium, and certain parks in return for Irvine's owning and developing the contiguous lands for low and medium density housing and for aquatic commercial uses. The proposed land swap was approved by the 1957 legislature subject to approval of the State Lands Commission. In 1966 the State Lands Commission withheld its approval on the grounds that the project would create commercial areas completely privately controlled and add to the preponderant private domination of the bay. The following year, however, under a new administration in Sacramento the Lands Commission reversed itself and approved the exchange.

Following such approval, a group known as the Friends of Upper Newport Bay was organized. It feared the exchange would result in both loss of shoreline to the public as well as loss of important wildlife habitat.

The Friends faced an uphill struggle in that the harbor district, the board of supervisors, the State Lands Commission and the state legislature had all given the necessary approval. All that appeared to remain for final clearance was court sanction of the land exchange and a dredging and filling agreement. This would be accomplished by a so-called "friendly lawsuit" filed in 1969 in the Orange County Superior

Court. What was to be a noncontroversial matter became a hotly contested adversary proceeding culminating in a significant appellate court decision of major importance in tideland litigation, and a splendid victory for Friends of Upper Newport Bay.

Joining the Friends of Upper Newport Bay in 1969 was an organization known as Orange County Foundation for Preservation of Public Property. The foundation assisted in the appeal of the trial court's judgment approving the land exchange. Due to the vehement opposition of the Friends of Upper Newport Bay, several most important events took place between the filing of the action and the trial court's decision. The Orange County Grand Jury had passed a resolution questioning the advisability of the exchange and the board of supervisors underwent a change of membership. The new board expressed a desire to rescind the exchange agreement as not being in the public interest and filed an appeal of the decision approving the exchange. Six citizens intervened in the county's appeal, contending that the exchange would result in Irvine's owning almost seven miles of prime waterfront along newly created harbor lines while providing only three miles or less of marginal waterfront property for the public. They were assisted by attorney Phillip S. Berry, former Sierra Club president, and Herman F. Selvin, former president of the state bar, represented Orange County in the appeal.

In February 1973 the court of appeal reversed the trial court's approval of the exchange after carefully reviewing California's tidelands trust. The court included in its grounds for reversal the fact that "... Orange County presently owned and controlled the entire shoreline of the bay area and that as a result of the exchange, it would be relinquishing two-thirds of that shoreline to be conveyed into private ownership."[3]

This decision was the turning point in the determined struggle to save Upper Newport Bay. Irvine as a result of the decision agreed to negotiate the sale of its wetlands long sought by conservation groups for a wildlife refuge. Backed by Friends of Upper Newport Bay and many other Orange County citizens, the State Department of Fish and Game negotiated the sale of 527 potentially highly developable acres from Irvine to the state for $3.48 million. Two hundred seventeen acres of tidelands held by Orange County were then added to complete the 744-acre wetlands preserve.

Credit for preserving what is today California's largest wetland ecological reserve goes primarily to the 100 dedicated citizen members of the Friends of Upper Newport Bay who gave directly of their time, talent, and money. Not only did they carry on an extensive campaign in educating public officials at the local, county, state and federal levels, but they also conducted public tours of Upper Newport Bay for some 15,000 people in addition to special tours for approximately 10,000 students. Working with the Orange County Foundation for Preservation of Public Property, the Friends were able to raise $80,000 for legal expenses to assist in the appeal. In addition, the Sierra Club and the citizen intervenors in the lawsuit played important roles in helping save Upper Newport Bay.

While the Upper Bay's major hurdle, that of public ownership, is resolved, there are still problems in achieving full utilization and restoration of the bay for wildlife preservation and for public enjoyment. The waters of the Upper Bay are threatened by storm drainage runoff from the massive adjacent urban population. Federal assistance to California and the Orange County communities encompassing the bay would help immeasurably to prevent such drainage pollution. It is also essential to protect the bluff land surrounding the Upper Bay from destructive development. To complete the task of protecting Upper Newport Bay, the citizen groups will continue to work until their goal is finally accomplished.

ELKHORN SLOUGH

One of the largest, most important wetlands remaining in California was saved from a major oil refinery being located near its shores—not on the issue of saving the wetland, but rather by citizen action groups interested in clean air.

Elkhorn Slough at Moss Landing in Monterey County, the second largest salt marsh in California, lies about 100 miles south of San Francisco on the edge of the Monterey Bay. During the bird migration in the fall and early spring, its 7-mile slough and 1,430-acre Salicornia Marsh attract over 90 species of birds, some rare and endangered, in addition to a variety of fish, clams, oysters and barnacles.

The biggest threat to Elkhorn Slough came in 1965 when Humble Oil, then the nation's largest marketer of petroleum products, announced plans to construct a $70 million refinery at Moss Landing.

Humble Oil, backed by the Salinas Chamber of Commerce, the Moss Landing Harbor District, and the Salinas Californian, one of the two daily newspapers in the county, proclaimed that Monterey County needed Humble Oil's refinery to provide a permanent labor force of 250–300 employees, plus 1,500 to 2,000 construction jobs and $1,300,000 in new tax revenues for the county. The proposed

[3] *Orange County vs. Heim* 30 C.A.3d 694 at p. 695.

450-acre refinery site was already zoned for heavy industry, with both Kaiser's Dolomite Processing Plant and P.G.&E.'s power plant operating in the area. All that was needed by Humble was a use permit from the county planning commission.

While early in 1965 the county's air pollution control advisory committee recommended the granting of the permit contingent upon meeting all air pollution standards imposed by the county, some 30 miles across the bay downwind from the Humble site, residents of the Monterey Peninsula doubted that a clean, odorless, non-smog producing plant could be built. Prevailing afternoon winds blow from the ocean in the summer months down the long, green Salinas Valley, and there were those who feared that such winds would carry damaging smog into fertile agricultural lands.

To meet the Humble challenge, there was formed on the Monterey Peninsula the Committee on Clean Air. Its president, Charles Kramer of Pebble Beach, a retired business executive, met with the board chairman of Humble Oil, who insisted that there was no air inversion in Monterey County and no danger of smog. Finding talks with Humble Oil officials to be fruitless, Kramer's committee encouraged the formation of a multi-county air pollution control district, and between March and July of 1965, 13,000 residents signed a petition against the proposed refinery. Public opinion was mounting on the Monterey Peninsula against the refinery and other petrochemical industries that might follow. The Monterey Peninsula Herald and its owner, Col. Allan Griffin, were strongly against Humble. This effort was joined by the Sierra Club, Audubon Society, the growers, American Association of University Women, League of Women Voters, and Salinas doctors' wives. Equally strong public opinion and support for Humble's plant were developing among business, labor, and Chamber of Commerce groups in Salinas, the county seat of Monterey County.

The nine member county planning commission's first meeting on the use permit was held early in 1965 and then continued until May. The chief questions it faced were:

1. Could a clean smog-proof refinery be built, and
2. Would there be an influx of associated petrochemical industries once the refinery was approved?

While air pollution consultants urged that an air pollution control district be immediately formed to enforce a strong clean air ordinance, Humble's attorney advised the planning commission that an oil refinery was "one of the most desirable industries that we can attract." A water expert from Humble added that there would be no oil spills from either crude oil or refined products being transported by tankers and barges or being unloaded through submerged marine pipelines. This was before Torrey Canyon.

On July 28, 1965, after a 4-hour hearing ended at midnight, the Monterey County Planning Commission by a 5–4 vote recommended against granting the use permit to Humble Oil. The swing vote was cast by Peter Cailloto, a local hardware merchant, whose business could be jeopardized by his decision, because of the strong support in Salinas for the plant. He nevertheless stated he was worried about air pollution and its damage to agriculture. "One fact is obvious," he said, "you can smell odors from a refinery."

The planning commission's decision was an upset victory for the refinery's opponents; the final decision, however, would be on the appeal to the board of supervisors. As the controversy progressed, Humble inserted large advertisements in the newspapers, urging people to ask their county supervisor to support the refinery.

To counteract Humble's campaign, Dr. Philip A. Leighton of Stanford University, one of the top air pollution experts in the country, pointed out in a series of articles in The Monterey Peninsula Herald how air pollution in other parts of California commenced with reduction of air visibility, followed by plant damage and then by eye irritation. In Monterey County he found that pollution was already at the plant damage threshold and he was particularly concerned with the location of the proposed refinery adjacent to the largest steam generating plant in the nation. When the P.G.&E. plant's expansion was completed, it would produce 2.1 million kilowatts, whose capacity would almost equal the 2.2 million kilowatts of all power plants in Los Angeles County which, when burning both crude oil and natural gas, emitted an average of 150 tons of nitrogen oxides daily. The availability of inexpensive crude oil at the refinery for the steam plant also concerned these experts who summarized their position with these words: "The question of preserving the priceless heritage of clean air versus the broadened tax base and jobs provided by industrialization has been faced by many other communities and resolved in favor of industrialization. These communities are now paying the price in terms of smog."[4]

The county supervisors before making their decision visited Anacortes, Wash., to witness first hand the operation of two refineries in that area.

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[4] The Monterey Peninsula Herald, August 25, 1965, Air Pollution Expert tells of Refinery Peril, Dr. Philip A. Leighton.

Finally, on September 3, 1965, D-Day arrived at the county board of supervisors where the hearing was conducted under the able leadership of its chairman, Tom Hudson, who, while personally against the project, was fair to all who spoke. After 13 hours of hearing and debates (the hardest fought in the history of the county), the 3–2 decision was finally reached at 3 a.m. to overrule the planning commission and grant the permit for the refinery.

While a broadened tax base and new jobs won out over clean air, the residents of the Montery Peninsula would not give up; they were fighting mad at the supervisors' decision and they immediately circulated a referendum petition to place the questions on the ballot, and within 21 days, 12,572 signatures were gathered. The referendum petition presented to the board of supervisors was rejected by the county counsel stating that the vote was an administrative rather than a legislative act and thus not subject to a referendum. To add a further roadblock, the county clerk would not proceed to verify the signatures on the petitions until instructed to do so by the county counsel. The matter went to court and a judge had to be brought in to hear the case after all Monterey County judges disqualified themselves.

On February 8, 1966, almost one year after Humble had announced its original plans to build the refinery, the court sustained the county counsel's decision. Still undaunted, a new avenue of approach was started to prevent construction of the refinery. The new tack was to obtain proxies and to carry the issue to the stockholders' meeting of Standard Oil of New Jersey, parent company of Humble Oil.

Humble Oil and Standard Oil of New Jersey received numerous letters with credit cards enclosed reminding the oil companies that the card holders did not want to patronize those who would inflict an oil refinery on Monterey Bay.

At last, sensing the severity of purpose, the unity and determination of Monterey County's clean air proponents, Humble began to quietly look elsewhere. On June 11, 1966 it announced receiving a favorable rezoning permit to enable it to locate its refinery near Rodeo on Suisun Bay. On May 17, 1966, Humble Oil finally announced abandonment of its proposed plant at Moss Landing on Elkhorn Slough in favor of a site at Benecia on Suisun Bay near other established Northern California oil refineries. Thus ended the historic battle to save clean air which started on February 15, 1965 and ended on May 17, 1966, and resulted in saving one of the great salt marshes from almost certain death. Humble's clean air problems followed it to Benecia.

The only new industry located on Elkhorn Slough since Humble's departure is a highly successful mariculture plant whose activities are compatible with the preservation of the wetland. Upland development and the possibility of new heavy industries continue to be a threat to Elkhorn Slough; however, Nature Conservancy has acquired some 500 acres within the salt marsh, and Moss Landing ranks among the 10 top priority wetlands for public acquisition in the report entitled, "Acquisition Priorities for the Coastal Wetland of California."[5]

SAN FRANCISCO BAY

The saving of San Francisco Bay, the most important natural harbor on the Pacific Coast, is an outstanding example of effective citizen education and adroit political action which resulted in legislation creating a permanent effective regional agency that preserves, protects, and provides for limited but wise development of the bay in the public interest.

When California was admitted to the Union in 1850, the bay's water surface consisted of 680 square miles. 100 years later, 200 square miles of this water surface was lost by man's activities in diking, filling, reclaiming, and polluting the bay. In addition, 17 square miles of tidal and submerged land had been filled along the waterfronts of bay area cities.

In 1850, 5,000 sea otter pelts were taken in San Francisco Bay. Today, no sea otters are found in the bay. While in 1900, the bay oyster harvest was 10 to 15 million pounds, there is no oyster harvest today. The once prominent San Francisco Bay shrimp industry is practically non-existent and there has been a loss of 1.8 million winter nesting water fowl. The various cities around the bay, by 1950, were slowly but surely looking to the San Francisco Bay as a thing to fill for expanded residential, commercial, and industrial development.

Particularly alarmed about this situation in 1959 was Mrs. Clark Kerr whose husband was then president of the University of California. She was accustomed to meeting at the San Francisco Airport distinguished visitors whom she would drive across the bay to the University of California at Berkeley. Frequently, they commented about the beauty and marvel of the bay, and Mrs. Kerr, while appreciating her visitors' remarks, was also aware not only of the plans of her own city of Berkeley to fill 2,000 acres of the bay, but the plans of other cities to expand into the bay. Mrs. Kerr, disturbed about this damage to a great resource, called a meeting of

[5] Cooperative Report, Bureau of Sport Fisheries and Wildlife—California Department of Fish and Game, April 1974.

university women, a retired Harvard economics professor, and a few conservationists concerned about the future of the bay. This was the start in 1959 of the save the San Francisco Bay effort.

The save-the-bay people's first success was dissuading the Berkeley City Council from filling in its wetlands. They then turned their eyes on the rest of the bay. At Mrs. Kerr's urging, the University of California's Institute of Governmental Affairs studied and published, under the able leadership of Mell Scott, "The Future of the San Francisco Bay,"[8] a comprehensive report showing how the bay's great resources were being destroyed.

How to stop the filling was a difficult regional problem in that the bay's shoreline involved the jurisdiction of nine counties and 32 cities, many having plans to extend their cities beyond their waterfronts. Also included in plans for bay filling were some of the most formidable financial giants of the west. One plan in San Mateo County alone called for an investment of $3 billion, which encompassed bulldozing down of the San Bruno Mountains near the San Francisco Airport to create more flatland for bay development.

There being no existing effective regional body to deal with the problem of bay fill, the save-the-bay group looked to their legislators at the state capitol for aid. Failing to obtain legislative assistance in 1963, they tried again in 1964, this time enlisting the support of Senator Eugene McAteer of San Francisco, a shrewd, tough, and able legislator. McAteer, knowing that he did not yet have sufficient support to control filling of the bay, was nevertheless able to get enacted temporary legislation creating a nine man study commission with a $75,000 appropriation whose purpose was to "define the public interest in the San Francisco Bay—to determine the effects of further filling upon navigation, fish, wildlife, and water pollution," and to report and to recommend legislation in 1965 to protect the public interest in the bay. To the 1965 legislature the study commission recommended that a San Francisco Bay conservation and development commission be established whose duty would be to formulate a comprehensive and enforceable plan to preserve the bay and protect it from piecemeal filling while the plan was being completed.

Coordinated planning for the future preservation, growth, and development of the entire bay area was important in 1965 and there was a need to impose a moratorium on further filling of the bay. Each of these issues would present formidable and perhaps insurmountable political opposition in the legislature. Senator McAteer wisely chose to make the agency's goal single purpose, confined only to the bay itself, and he skirted the question of a moratorium on all filling in the bay by providing power to regulate filling through a permit system. His 1965 legislation was carefully drafted so that it could not be hamstrung by opposing lobbyists.

The save-the-bay group working very hard to muster support in Sacramento was assisted by a popular San Francisco disc jockey who plugged "Save the Bay" daily on his 6 to 9 a.m. show, even calling the governor out of bed to give his comments on the bay! Small sackfuls of sand arrived in legislators' offices with the message, "You'll wonder where the water went if you fill the bay with sediment." Bus loads of people attended all of the committee hearings and, after an extremely hard fought battle, the bill known as the McAteer–Petris Act was passed and became law in June 1965, providing for developing a long range plan for the San Francisco Bay to be prepared by the new bay conservation and development commission. Its members were both elected and appointed, many of them being representatives of governmental agencies—federal, state, county, and city. During the planning stage, anyone wishing to fill or remove materials from the bay was required to obtain a permit from the commission.

In January 1969 the plan, consisting of a set of policies for the future of the bay, was finished and submitted to the legislature. Once again, a major battle ensued, but this time without the leadership of Senator McAteer, who had died. The developers and owners of bay lands regarded the 1969 session of the legislature the last and final chance to forestall regulations that would prevent them from carrying out their development plans for the bay. Likewise, the backers of the bill were most cognizant that its passage would be the final legislative step in providing the guidelines and governmental organization necessary to save the bay. Consequently, both sides worked long and hard in the legislative halls of Sacramento.

After a fierce legislative struggle, followed by a change of leadership in the state senate, people became aroused and a petition three miles long containing over 250,000 signatures was presented to the governor demanding that the bay be saved. Finally, legislation was approved making the commission a permanent body. The law, when signed by Governor Reagan established the San Francisco Bay Conservation and Development Commission (BCDC) giving it regulatory powers over all filling and dredging in the bay, limited jurisdiction over substantial development within a 100-foot strip

[8] Published by University of California Institute of Governmental Studies, October 1963.

inland from the bay, and limited jurisdiction over proposed filling of salt ponds and managed wetlands.

(The Bay Conservation and Development Commission's activities, experience, and personnel laid the foundation for Proposition 20, the Coastal Zone Conservation Act of 1972.)

Of the gallant struggle started by the University woman in Berkeley in 1959, Russell Train, chairman of the Council on Environmental Quality stated:

> Concerned citizens demonstrated a vigor of purpose and a tenacity that outlasted setbacks, and persisted year after year and session after session until the legislature responded. It is as though, having come to the end of a long Westward journey of conquering the land, California contemplated the bay and decided to let it live.[7]

PROPOSITION 20

The November 1972 election in California marked the passage of Proposition 20, California's Coastline Protection Initiative. For more than a century there have been increasing demands and competing pressures for commercial, industrial, residential and recreational uses of the natural resources along California's 1,072-mile shoreline. Committees of the legislature as well as numerous coastal study commissions for 25 years had repeatedly pointed out the inability of local government to respond to the regional and statewide needs to protect California's magnificent and divergent coastal resources.

Conservation groups having been unable in 1970 and 1971 to obtain coastline protection in Sacramento made a herculean effort in 1972 but could not overcome the strength of major lobbying forces in Sacramento. Not to be outdone, California's Coastal Alliance, whose membership induced over 100 civic, conservation, sports, business, and some labor organizations, used California's direct initiative and obtained 500,000 signatures to qualify the Coastal Protection measure for the November ballot. The Alliance under the able leadership of its president, Janet Adams of San Mateo, was able to get the initiative passed by a 55 percent statewide vote. The people of California through Proposition 20 said:

> The permanent protection of the remaining natural and scenic resources of the coastal zone is a paramount concern to present and future residents of the state and nation; and
>
> It is the policy of the state to preserve, protect, and where possible, to restore the resources of the coastal zone for the enjoyment of the current and succeeding generations.[8]

[7] The Saving of the San Francisco Bay, by Rice Odell, published by Conservation Foundation—Foreword by Russell Train, p. VIII.

[8] Section 27001 California Public Resources Code

Proposition 20 did not provide a permanent solution to the coast's problems. What it did do was establish temporary commissions to plan for the future and to temporarily control development by requiring that Coastal Commissions:

1. Prepare a plan for the future of the California coast to be submitted to the legislature before January 1, 1976.
2. Control all development within the state's coastal waters and on land within 1,000 yards of the coast to insure that unwise development does not make the coastal plan useless before it can be completed.

Proposition 20 created one state and six regional commissions which cease to function after December 31, 1976 unless continued by the legislature.

The state commission's able chairman is Melvin B. Lane, who served with distinction as chairman of BCDC. Lane brought with him from BCDC its articulate and experienced executive director, Joseph Bodovitz, who serves as an executive director of the state commission. Also BCDC's former chief planner, Jack Shoup, heads up the planning effort of the state coastal commission.

Public input and citizen participation are most noticeable in both the planning and permit procedures of the coastal commissions.

In developing each of the elements of the preliminary plan extensive public hearings were held by each regional commission as well as by the state commission.

Nine elements of the coastal plan are:

Marine environment
Coastal land environment
Geology of the coastal zone
Appearance and design
Recreation
Energy
Transportation
Intensity of Development
Government organization, powers and funding necessary to carry out the coastal plan.

Of particular interest to protectors of estuaries is that section of the plan dealing with coastal waters, estuaries, and wetlands under the marine element: "All remaining coastal estuaries, wetlands and other buffer areas necessary to protect wetlands and their wildlife and bird habitat values shall be preserved, enhanced, and, when possible, restored."[9]

[9] Preliminary Coastal Plan, p. 39 (Hearing California Coastal Zone Conservation Commissions).

To carry out this objective, the plan proposes that before any alteration of wetlands is permitted an overall plan of the wetland must be prepared and approved by the state commission. New developments in wetlands would be only permitted after there is demonstrated a statewide need and no feasible alternative. The plan also calls for control of development in upland areas adjacent to estuaries so as to prevent adverse impact on estuarine values.

The preliminary coastal plan has been widely distributed throughout the state. In the history of California, no other plan proposed to be submitted to the legislature for consideration and approval has had as much public input and review as the preliminary coastal plan. Public hearings conducted throughout the state encourage citizen participation and input. Many of the meetings have been held at night to enable working people to participate. Individuals and organizations have provided a vast amount of letters, statements, and position papers regarding the plan. As a result of such public input, the preliminary plan will be revised and improved before presentation to the legislature.

Hearings on permit applications for developments have also provided much opportunity for individuals and organizations to participate and present their views to the regional commissions and to the state commission on the appeals, and at each meeting of the state as well as the regional commissions 15 minutes time is set aside to permit any citizen or organization to address the coastal commission on any matter other than specific matters that may be pending before that commission.

The public input at the preliminary coastal plan hearings proved to be enlightening for the individuals and groups who appeared as well as for the commissioners listening to the public comment. Commissioners were berated as being "socialists," "communists," and "dictators", as well as saviors of the coasts, estuaries, plankton, coastal bluffs, and the ocean. The public learned that the coastal plan was a sincere and reasonable effort to save the coast and not, as some critics commented, "a land grab by a starry-eyed group of self-perpetuating bureaucrats." The commissions learned that the plan as presented was perhaps too bulky, was not fully understood by many citizens, and was not likely in its preliminary form to be understood or appreciated by the legislature.

The revised plan was to be presented to the legislature before January 1, 1976. With more than 80 percent of California's population living within a 30-minute drive, the coast needs legal protection. Hopefully, an intelligent support group of informed citizens of California, having lived through and participated fully in the growing pains of the coastal commission will unite to give California the kind of legislation needed. Failure to enact meaningful coastal legislation will result in a return to the wasteful, piecemeal, sprawling development that has overrun many parts of the California coast, congesting coastal streets, walling off coastal vistas, filling bays and estuaries, and denying public access to the coastline.

The decision of the California legislature will be anxiously awaited by users of coastal resources throughout our nation.

WETLANDS AND THE COURTS

The judiciary in California, as elsewhere in the nation, has played a most significant role in interpreting and enforcing environmental legislation. Citizen groups have contributed much in bringing the issues to the attention of the courts and in helping to finance environmental litigation.

The tidelands and wetlands of California have for years been subject to considerable litigation. Title to the tidelands was acquired by the state upon its admission to the Union in 1850. By legislative enactment in 1868 and subsequent amendments the state's tidelands were impressed with a public trust for navigation, commerce, and fisheries. Tidelands embraced in the California statutes have been interpreted by the courts to: ". . . extend from the Oregon line to Mexico and include the shores of bays and navigable streams as far up as tide water goes and until it meets the lands made swampy by the overflow of freshwater streams."[10]

Among the significant opinions concerning tidelands in which citizen groups played a vital role was the case of Marks v. Whitney[11] decided by the California Supreme Court in 1971. This was an action to quiet title by the plaintiff Marks who owned lands on Tomales Bay, lying between the mean low and mean high tide, a portion of which were in front of defendant Whitney's property facing the bay. Marks sought a declaration from the court that he had a right to fill and develop the tidelands.

The lower court held that defendant Whitney did not have standing to raise the issue that such tidelands were subject to the public trust. The court found that Whitney had an easement to use a wharf across the tidelands property of Marks' subject to Marks' right to fill and develop the tidelands.

Actively participating in the appeal of the trial

[10] People v. California Fish Co. 166 Cal. 576 at p. 591
[11] 6 C3d. 251

court's decision was the Sierra Club on behalf of its 60,000 members, who asked the court to declare the tidelands of Marks' to be subject to the public trust and to find that Whitney had standing to raise the issue. The Sierra Club also asked the court to determine the extent and scope of public easements in navigable waters over tidelands.

The appellate court took judicial notice that Whitney's lands lying between the lines of mean high and low tide were tidelands and were, therefore, impressed with the public trust. This court pointed out that the public trust in tidelands for navigation, commerce and fisheries has been held to include the right to fish, bathe, hunt, swim, and use for boating and general recreational purposes. Of particular interest to protectors of wetland is this language:

> There is a growing public recognition that one of the most important public uses of the tidelands—a use encompassed within the tideland trust—is the preservation of those lands in their natural state, so they may serve as ecological units for scientific study, as open space and as environments which provide food and habitat for birds and marine life, and which favorably affect the scenery and climate of the area.[13]

It also found that Whitney did have standing to sue in that the relief sought by Marks in filling and developing the tidelands would take away Whitney's rights, to which he was entitled as a member of the general public.

A bombshell in environmental law in California is the now famous Friends of Mamouth v. Board of Supervisors[13] involving the construction of a ski lodge in Mono County. The statewide impact of the California Supreme Court's decision is of major concern to wetland protectors as well as to all environmentalists.

Here the developer had obtained a conditional use permit for the construction of two multi-storied condominiums without there having been issued an environmental impact report under California's 1970 Environmental Quality Act (CEQA).[14] The Friends of Mamouth, a citizen action group, contended that CEQA applied to private as well as public projects. The National Environmental Protection Act (NEPA)[15] upon which the California Act was modeled applies to public, not private projects.

The California Supreme Court held that state and local governmental agencies must file an environmental impact report for all projects both public and private which require a governmental permit, lease, or other entitlement for use if such activities may have a significant effect on the environment. Proposed developments in wetlands having a significant effect on the environment are governed by CEQA. Developments on the San Francisco Bay, however, are subject to BCDC (The San Francisco Bay Conservation and Development Commission) and the Coastal Zone Conservation Act[16] governs developments lying within 3,000 feet inland from the mean high tide.

In Lane v. City of Redondo Beach[17] aggrieved citizens established that a court may grant declaratory relief to protect the public's right of access to tidelands and navigable waters.

The city of Redondo Beach had passed an ordinance permitting the closing off of certain city streets. The redevelopment agency under its redevelopment plan had sold off the land on which the streets were located and structures on the land had been completed. The plaintiffs contended that such action denied easy access to the beach for lower income citizens, children, and senior citizens in violation of their right under the California constitution[18] and the government code[19] guaranteeing free and unobstructed access to navigable waters from public streets and highways of a city.

The city countered that it had the right to pass the ordinance closing the streets and unless there was abuse of discretion, fraud, or an ultra vires act the plaintiffs could not attack the city's action. Not so, said the appellate court, adding that a municipality may close off a public street but it does not have the right to close off public access to tidelands or navigable waters.

> The basic purpose of entrusting tidelands to municipalities in trust, is to insure the right of free public access to tidelands or navigable waters. (Calif. Const. Art. XV, Sec. 2 & 3) The object of the trust is destroyed if a municipality . . . can deprive the public of its right of access to tidelands or navigable waters.[20]

Three young men from San Francisco's Lowell High School, disturbed about a development overlooking Lake Merced south of Golden Gate Park, decided to try and stop the project which they felt would cause damage to the lake. Without finances or experience they nevertheless won a $100,000 settlement which was put into a trust fund for coastal environmental protection.

In 1971, for an Eagle Scout project, a 17-year-old boy, Allan Riley, produced a film and report on

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[13] Marks v. Whitney, 6 Cal. 3d 251 at p. 259
[13] 8 Cal. 3d 247
[14] Sec. 2100-21165—California Public Resources Code
[15] 42 USC 4321
[16] Sec. 2700-27650—California Public Resources Code
[17] Court of Appeal, Second Appellate District 2nd Civ. No. 45240.
[18] California Constitution, Article XV, Section 2.
[19] California Government Code, Sec. 39933.
[20] Lane v. City of Redondo Beach, ibid.

Lake Merced. He wanted to clean up and preserve the lake and was concerned about a large condominium development under construction on the lake's edge. While Allan was checking various agencies and being brushed off as some kind of "an ecology nut," Proposition 20, California's Coastal Protection Act, became law. He found that the Act provided that if a body of water, not subject to tidal action lies within 3,000 feet inland from the coastline, (i.e., within the coastal zone permit area), the body of water together with a strip 1,000 feet around it shall also be included. He contended that a coastal commission permit was required for such development and one had not been obtained, so he went to court and won a preliminary injunction forcing the developer to seek a permit. For one and a half years Allan carried on the fight alone until he went off to college; then he enlisted two of his former Lowell High School friends, Jonathan Holt and George Duesdieker, to carry on. These young men worked very hard, and for a month never went to bed before 3 a.m. in their diligent efforts to gather all essential facts in preparation for the hearing before the regional coastal commission.

Disappointed that the regional commission granted the permit to the developer, they nevertheless pursued the matter, taking an appeal to the state coastal commission, basing their appeal on inadequate sewage disposal, damage to bird habitat in the lake, traffic density, and earthquake hazard.

The state commission, by a vote of 11–1, denied their appeal in 1973, but the youths would not give up. They interested a San Francisco attorney, Margaret Halloran, in their cause. Struck by their enthusiasm, she represented them in suing both the developer and the coastal commission, challenging the commission's procedures in granting the permit. San Francisco Superior Court Judge Ira Brown issued an injunction stopping the project on October 1, 1973, and then took the matter under submission for 8 months. On June 5, 1974, he informed the parties that he was intending to invalidate the permit and order the case back to the commission. The delay was costing the developers vast sums of money in interest rates alone, so the developer settled in cash for $100,000 with no strings attached. The youths could have kept the money but they preferred to see it go into a trust fund to help environmental causes. Attorney Halloran stated that, without the tremendous research and the fact-gathering by the youths, the case would not have been won. These Lowell High School students proved how effective youth can be in pursuing their legal remedies to a conclusion. They paved the way for others by setting aside their winnings in an environmental trust fund.

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LEGAL ASPECTS

LAND USE CONTROLS AND WATER QUALITY IN THE ESTUARINE ZONE

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ABSTRACT

A complex institutional problem has arisen in the management of estuarine resources due to overlapping and contradictory regulatory programs at the federal, state, and local levels. A contributing factor to this problem is the split between regional and community-focused resource management involving state and local land use planning, and specific resource management programs involving federal controls over air and water, and federal review of major construction projects affecting the environment. Noting that state and local government initiatives in control of lands adjacent to estuaries are increasing, and that the federal Coastal Zone Management Act of 1972 was designed to bridge the fields of regional and community-focused management and federal resource management both technically and institutionally, the paper concludes that state-level coastal zone management efforts should be upgraded. Further, coordination requirements included in many federal laws should be given more study and financial support to make them effective.

INTRODUCTION

Most water quality issues have a land use component to them. Site selection for an industrial plant, modification of the land-water interface (the angle and shape of the land being "washed" by the water), and the land use activities affecting water runoff and drainage all affect the quality of the receiving water. The impact of land use on water quality is reviewed by an array of institutions developed in the United States over many years. This paper argues that *our key problem in dealing with estuarine resources is an institutional rather than a technical one.* The technical issues of environmental impact assessment, judicial clarity of private property rights, and others are important, but the primary question is: Who's in charge? This institutional problem arises from numerous conflicting federal and state laws, a federalism system where power is split between states and the federal government, and the current changing role of state and local governments in resource management activities.

For the estuarine zone, the institutional problem arises because of two different factors:

1) Legally apportioned responsibilities among levels of government are based on geographic land-water interactions; and

2) Specific resource management (air and water quality, physical facility development) tends to be considered separately from community-focused resource planning and management.

There are three types of land-water interaction in the estuarine zone, each of which has different sets of institutions for resolving disputes. The first relates to water drainage, water capture, or rights to water use. Private law has developed to accommodate rights of adjoining neighbors in the exercise of these water-related interests. Further, local planning and districting laws frequently aid in accommodating problems between landowners seeking to use the same resource. These water use problems are normally controlled by adjudicating private rights in court, and by actions of local planning and zoning agencies or special districts.

A second area of land-water interaction is called "foreshore," bank, or tidelands where there is a mixture of state and private ownership. Occasionally, rights are totally in one party or another. Sometimes a "public trust" is established and private rights may only be exercised subject to an overriding public interest. Of late, the foreshore area is managed primarily at the state level with federal review where navigable waters are involved.

A third area where land and water interact in the estuarine zone involves waters and waterbottoms in streams, lakes, bays, and other coastal waters where state ownership of waterbottoms and natural resources coexists with the federal navigational servi-

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tude. Thus, state law normally controls the resources of the area (fish, minerals, and water consumption) but the federal servitude requires review of most actions to determine impact upon federal navigation and environmental interests.

It is seen that each area of land-water interaction—water use by the landowner, the foreshore, and waterbottoms—has its own primary mixture of institutions regulating and managing the resources. Estuaries, and their associated wetlands and uplands, can, and usually do, involve all three areas thus magnifying the institutional problem.

Critical institutional problems arise because air and water quality issues and physical facility development proposals are managed separately from community-focused resource planning issues. Federal jurisdiction is primarily concerned with the former method of management whereas state and local governments are primarily concerned with the latter.

The term "community-focused resource planning" refers to a number of factors for which it is difficult to find one all-inclusive term. It applies, fundamentally, to human needs in an urban or urban-fringe context, where the needs are reflected in types of land use planning and controls. It refers to procedures to meet housing needs for a diverse population and to meet police, fire, and health standards. It can reflect community attitudes about growth, limits to growth, and quality of construction or aesthetic principles. It can reflect concepts of "key area" or "areas of critical environmental concern." It can consider employment, education, economic and other social needs as a function of land use considerations.

Community-focused resource planning stands apart from specific resource management such as air and water quality controls, water resource development, fish and wildlife impact evaluations, and specific transportation/facility project developments. Specific resource management programs strive for technical precision through alleged objective criteria based on applied research, pilot projects, models, and so forth. They are normally implemented through federal laws and regulations with decisions made by technically trained federal, state, or local officals. On the other hand, community-focused resource planning is controlled almost exclusively by the political process. Implementation of precise technical standards will almost always yield to a hardship case, strong public (or political) sentiments forcing a decision one way or the other, or an emergency situation.

Control of land uses which affect estuarine water quality is caught in a crossfire between the specific resource management functions of federal agencies (EPA—water qua[illegible] U.S. Fish and Wildlife Service—fish-habitat [illegible]ovement; Corps of Engineers—navigation [illegible]ovement) and community-focused planning considerations such as the need for higher employment, protection of a scenic stream, or housing demands. Local governments responsible for community planning have hundreds of federal regulations and inducement programs to deal with, many of which are competing or contradictory. The difficult struggle in the area of land use controls is to determine when a consideration of community-focused needs should, or could, override specific resource quality standards. Or, to put the case the other way, when should a federal standard, for example, the requirement that structures be elevated above predicted flood stages within a flood plain, control the flexibility of local government to respond to a local community need? The laws, institutions, and administration of specific federal resource management programs and local community-focused resource planning programs reflect this struggle daily.

This paper analyzes this struggle in the context of coastal and estuarine land use problems. For practical and constitutional reasons, a major overhaul of the current system of managing land-water interaction problems is not recommended. However, it is suggested that there are three ways in which the structure can be improved. First, it is recognized that the state government could play a stronger role as a mediator where local community resource programs differ. Second, it is suggested that coordination between differing specific management functions be upgraded. Third, there is a need to improve descriptions of experience throughout the nation in certain technical matters which can aid decision-making where land-water interaction problems are involved.

To show why these particular institutional problems need attention and to describe ways in which the problems currently arise, four types of management processes used in the estuarine zone are discussed, with emphasis on developments over the last five years. First, the paper discusses federal controls over activities affecting wetlands. Second, major project review at the federal level is discussed. Third, recent developments and initiatives at the local and state level are outlined. Finally, the Coastal Zone Management Act of 1972, potentially an important tool in the future, is discussed. The recommendations stated briefly above are discussed in more detail in the conclusion.

FEDERAL CONTROLS OVER ACTIVITIES AFFECTING WETLANDS

Most marshes and estuarine areas are near or associated with bodies of water that are considered navigable. Tidal waters are considered navigable as are streams capable of conveying any kind of commerce. Where there are navigable waters the United States government has regulatory jurisdiction under the commerce clause of the U.S. Constitution.[1] In recognition of this authority to regulate commerce Congress has granted significant authority to executive agencies to deal with specific resource management activities. For example, the U.S. Army Corps of Engineers regulates activities affecting navigable waters and navigation.[2] The Environmental Protection Agency looks at water quality[3] and air quality,[4] among other things. The U.S. Fish and Wildlife Service and the National Marine Fisheries Service are concerned with fish and wildlife resources[5] of the nation. Each of these agencies, given certain specific authorities and responsibilities by Congress, analyzes the effect proposed activities may have upon these resources by balancing the need for the particular activity with the impact on the resource.

In the last five years Congress, the courts, and administrators have attempted valiantly to upgrade the federal review procedure and make it a workable one. Many of the laws and procedures are still new and many details of this review process have not been fully worked out.

With respect to most activities affecting wetlands primary jurisdiction is in the Army Corps of Engineers under the Rivers and Harbors Act of 1899.[6] When bridges or causeways are involved, the Coast Guard has primary jurisdiction.[7] Any local government or private entity wishing to perform work (water diversions, piers, bulkheads and jetties, drainage, dredging, and others) must apply to the Corps of Engineers for a permit before that work may begin. Originally, the Corps evaluated projects from the standpoint of navigational interests alone. In the last 20 years, however, changes have occurred in this procedure which have substantially expanded it. These will be briefly described.

The Fish and Wildlife Coordination Act[8] was originally passed in 1934 and has been amended numerous times since then. It requires that the director of the United States Fish and Wildlife Service, the National Marine Fisheries Service,[9] and the chief official of the state resource agency concerned with fish and wildlife resources provide comment to the Corps of Engineers on the effect of the proposed project on fish and wildlife resources. These comments are attached to the report of the district engineer and frequently form the basis for denials, compromises, or the imposition of mitigative features as permit conditions and other arrangements between the applicant and the Corps of Engineers. The past decade has seen significant growth in the fish and wildlife review procedure. In August 1974, the U.S. Fish and Wildlife Service published a set of guidelines[10] developed in the past 10 years to assist field personnel review applications for Corps permits.

In recent years other events have occurred requiring that interests beyond navigation be considered by the Corps of Engineers prior to approval of a permit. In 1970, Zabel v. Tabb,[11] decided by the U.S. Fifth Circuit Court of Appeals, held that the Corps of Engineers may deny a permit for activities in navigable waters on ecological grounds alone. It recognized that the Corps must consider the congressional intent in the Fish and Wildlife Coordination Act and the National Environmental Policy Act in its decisionmaking process.

In 1972, three acts were passed, all of which will affect aspects of Corps procedures: the Ocean Dumping Act,[12] the Federal Water Pollution Control Act,[13] and the Coastal Zone Management Act.[14] The Ocean Dumping Act requires the Corps of Engineers to apply Environmental Protection Agency standards and criteria in approving ocean disposal of dredge spoil materials where the transport for dumping passes through U.S. territorial waters.[15] Similarly, under the Federal Water Pollution Control Act of 1972, the Corps must apply EPA criteria in allowing disposal of dredge spoils in navigable waters.[16] Under the Coastal Zone Management Act of 1972, Congress has given states the primary responsibility for determining land and water uses affecting the coastal zone.[17] (The potential effect of this new law is discussed in more detail later.) The precise impact of these three new laws passed in 1972 is still being debated by the Corps of Engineers and other agencies.

In response to these many changes, the Corps of Engineers began modifying its procedures, first, by expanding the definition of the word "navigable waters" to align with the case law developed by U.S. courts in defining the term. By regulation,[18] all waters up to the mean high tide line, including wetlands wholly or partially covered at high tide are included, whether privately or publicly owned. Further, waters which are "navigable-in-fact," and capable of supporting commerce or which in the past, or potentially in the future can become "navigable-in-fact" are included. Most recently the Corps of Engineers issued new guidelines expanding its scope of review over activities affecting navigable waters[19] which provide a higher standard of review when wetlands or marshes are involved.[20]

Currently, wetlands control at the federal level involves the Corps of Engineers (or Coast Guard) as the primary agency with comments, or input coming from many other interests. At the federal level input is received from the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the Environmental Protection Agency, and, where the nature of the application requires, other agencies of the federal government having an interest. Further, the Corps receives input from state and local agencies having an interest in the project application, the number of agencies varying with the state. Beyond the review exercised by government agencies, the Corps becomes the focal point for pressure from the applicant to have his project approved, and pressure from public interest, environmental, or other groups who oppose the change in the wetlands environment.

If a proposed project is large and potentially damaging to the environment in a "significant" way, or if there is a great deal of public controversy surrounding a proposed project, the Corps may decide that an environmental impact statement must be prepared under the National Environmental Policy Act of 1969.[21] The decision to prepare such a statement is discretionary with the federal agency depending on its interpretation of whether a permit allowing construction is a "major Federal action significantly affecting the quality of the human environment." If an environmental impact statement is prepared the same agencies review the draft statement, or provide input to the Corps as in the case of general permits for activities in navigable waters. The agency and public comments tend to relate to the adequacy of the environmental impact statement as well as the substantive environmental issues. Further, the procedures followed are more specific, resulting, usually, in a more detailed and thorough review. (Review of major public works projects is discussed in the next section.)

Three key matters involving the Corps review process just described will have to be addressed in the coming few years. First, the review process may be too narrow to allow for sound decisions. It is project oriented--the responses relate to a specific action at a particular time. Also, the review is single-resource oriented, i.e., the focus of attention is the single purpose the project is to serve or the effect the project has upon a single resource such as a wildlife habitat affecting one species. Often, impacts on the ecosystem as a whole are not evaluated. Further, the procedure seems deficient in that regional considerations and community-focused resource planning dimensions of review are missing. Receiving input on a specific project proposal from varieties of agencies may not provide the overview necessary for sound management and decisionmaking.

The second matter needing attention in the next few years is the role of the Environmental Protection Agency. In addition to reviewing dredge spoil disposal practices discussed above, EPA reviews all dredging permits to determine impact on water quality.[22] This agency also influences land use decisions greatly through required planning programs.[23] These powers have yet to be implemented for the most part. For example, the New Orleans District of the Corps of Engineers does not get direct input from EPA, but EPA provides information to the Fish and Wildlife Service which combines the information with its review. At the Washington level, there is debate over how extensive EPA and Corps control over dredge spoil disposal should be. Despite these uncertainties, EPA's recent statements regarding protection of the nation's wetlands[24] and land use implications of EPA programs[25] indicate that this agency's review of wetlands decisions will increase in the future.

A third aspect of the federal wetlands control program which may change dramatically in the next few years is the role of state and local governments. Though some states make very specific recommendations to the Corps of Engineers on these matters, other states have not yet developed specific programs. Most states are upgrading current efforts or developing new ones to more effectively manage wetland resources. Some assistance may come as the Coastal Zone Management Act (to be discussed later) is implemented. A key question is whether state authority will increase and replace aspects of federal government review, thus shifting the focus of attention from federal agencies to state agencies. It is possible that states will be given greater consideration and perhaps be the determinative voice in the federal review process. Further, they may be able to better address regional and community-focused considerations.

MAJOR FEDERAL PROJECT REVIEW

Operating parallel to the review of individual permit applications for activities affecting navigable waters is the planning and implementation of major public works projects, normally dealing with utility or transportation development, which affect coastal zone and estuarine resources. Most of these involve significant modification of the land-water interface with resulting changes in water movement and circulation and with notable effects on geology, water chemistry, and biology. Projects in this category include river channel improvement; new roads and highways crossing estuarine areas; large fill projects

for airports or port improvements; dams and reservoirs for irrigation and flood protection; major shore protection works to offset erosion, accretion, and sedimentation; stream channelization for drainage; and other kinds of activities.

The Corps of Engineers and other major federal agencies are normally responsible for these kinds of activities. They do not apply for a permit as discussed in the previous section. For the most part Congress determines the rules to be used in deciding when, where, and how a major public works project using federal funds is to be developed. For example, the Department of Transportation administers the Federal-Aid Highway Act[26] which contains numerous requirements for consideration of environmental values in planning and constructing highways. Similarly, the Federal Aviation Administration in airport site selection, the Federal Power Commission in power plant site decisions, and other such agency determinations follow congressional guidelines and procedures. (In the case of the Corps of Engineers, Soil Conservation Service, and others, where Congress has not established specific guidelines in an organic law, the U.S. Water Resources Council has promulgated "Principles and Standards for Planning Water and Related Land Resources"[27] to help establish if a proposed project is in the public interest.) How are federal decisions on major public works projects reviewed for impact on wetlands and estuarine water quality?

The key review of major federal projects is done pursuant to the National Environmental Policy Act (NEPA).[28] Under that act, all federal projects which significantly affect the quality of the human environment must be preceded by an environmental assessment and the preparation of an environmental impact statement. Hundreds of law suits have been filed by environmental protection organizations in recent years using NEPA and the impact statement requirements as their basis.[29] The Council on Environmental Quality which administers the impact statement procedure, has codified much of the case law under this process in their recent guidelines.[30] Further, federal regulations coming from numerous construction agencies over the past year have stressed procedures within that agency for making NEPA reviews.[31]

NEPA review can be criticized from three standpoints. First, the federal agency promoting and developing the project is responsible for preparing the impact statement. They are responsible for conducting an impartial reevaluation of the merits of the project long after the inital decision to proceed with the project has been made. Hence, federal agencies are frequently in the awkward position of trying to respond to the pressures for project review and analysis on environmental grounds and meet requirements under law to proceed with the project.

Second, the procedure of major federal project review is fundamentally a free-for-all. There is no executive guidance to agencies. Major federal agencies which oppose one another on specific projects—e.g., the Corps of Engineers which is sponsoring a major dredging project and the U.S. Fish and Wildlife Service which opposes it—have no arbiter to which to take their claim. The issue frequently becomes political or ends up in litigation. Occasionally through negotiation, interagency agreements on projects are arranged but this is often an exercise in finding a middleground the agencies can live with which may or may not represent the best public interests.

Third, and perhaps the fundamental problem with the procedure for reviewing major federal projects is its "project orientation." The federal agency sponsoring the project must comply with a law designed to promote the project. Congress has passed numerous flood control acts, highway development acts, navigation improvement bills, and many others. The agencies implementing the laws are engineering-oriented agencies with specialized functions. Hence, authority for resource development projects is spread among special-function agencies. This impedes development of a broader approach to determining project need and the consideration of values beyond those immediately associated with the project. What may be missing is a more meaningful role for state and local government in looking at regional considerations and community-focused needs.

LOCAL AND STATE INITIATIVES IN PLANNING AND MANAGEMENT

Theoretically, considerations of community-focused needs and regional concerns are provided by local and state agencies through planning and land use control laws (zoning, subdivision control, eminent domain).[32] Planning and zoning controls arose to serve the need of making land uses in an urban environment compatible. Today, planning and zoning concepts are being applied to new areas of concern arising primarily outside of urban areas.

In the last five years these controls have been significantly expanded to cover coastal zone, wetlands, and estuarine areas. The following are representative examples. Wisconsin passed a Shorelands Zoning Act[34] creating standards for local governmental units to control disturbance of wetlands and shorelines. Delaware recently took action to protect its beach dunes[35] along the Atlantic Ocean. The

State of Washington has passed a Shorelands Management Act[36] which controls all development activities from the line of vegetation to 200 feet inland along the shores of the ocean, bays, and lakes of the state. California has passed recently the California Coastal Zone Conservation Act[37] which, in a zone extending from the 3-mile territorial limit to 1,000 meters inland requires permits for all development activities. The State of Florida passed the Environmental Land and Water Management Act[38] in 1972 which delineates areas of critical state concern and developments of regional impact for application of state and regional policies. Maine has passed a Site Location Law[39] controlling major facility development. Hawaii[40] and Vermont[41] have established commissions which review all major land use activities in these states.

In most of the examples there is a mixture of control activity between state and substate units of government. Traditionally, state law provides general guidance and limits of authority while implementation is at a lower level of government. The courts have upheld these laws as valid exercises of governmental power[42] but occasionally courts restrict the exercise of that power to protect the property rights of the individual affected.[43] Thus, states and local governments are experimenting with new laws and ordinances in controlling key areas and resources normally found outside of the urban environment. This trend will probably continue.

State and local initiatives to plan and manage coastal regions, critical areas, or resources in a key area, must deal with specific resource or project management under federal laws whenever navigable waters or federally assisted programs are involved. For example, in California's coastal area, many activities managed by the California Coastal Zone Conservation Commission are also reviewed by federal agencies having resource or project functions within that region. Potentially, state and local management of regional or community-focused resources can conflict with resource and project management exercised by federal agencies. This has occurred in California where Interior Department's plans for Outer Continental Shelf oil development and California's plans for coastal zone management are bound to conflict.[44] This becomes a struggle between the state's exercise of its police power and the federal government's powers to regulate commerce among the states.

This state-federal struggle gives rise to technical, legal and institutional problems. At the technical level, frequently incompatible results arise from an evaluation of the goals and needs of a particular area (done by the state or local unit) and the analysis of resource or project development under federal standards and criteria. The perspectives of the respective agencies are quite different. From a legal and institutional standpoint, clarification is needed to distinguish between regional or community-focused decisions made at the state and local level and the resource and project management decisions exercised at the federal level. It is uncertain whether the courts must choose between the two or allow the two decision processes to exist side-by-side.[45] Congress may, as a matter of policy, begin to restrict and reduce federal management roles in an effort to upgrade the role of state and local government. With strengthened state and local programs emerging and demanding an effective voice in decisionmaking, a shift in power may evolve over a period of years. This would constitute a reversal of a trend started in the early part of this century whereby Congress used its powers under the interstate commerce clause to exercise many resource management functions at the federal level.

FEDERAL COASTAL ZONE MANAGEMENT ACT

If the state and local initiatives described are to succeed as the mode for regional and community focused management, they must be legally and technically prepared for the job. One law specifically designed to encourage and upgrade state and local initiative in this area is the Coastal Zone Management Act of 1972,[46] a quietly passed, almost unnoticed, bill. The 30 coastal and Great Lakes states (territories and possessions as well) can apply for assistance in the development and implementation of coastal management programs. The key purposes of the law are to balance environmental protection and economic development objectives in the land and water use decisions in the coastal zone, and to upgrade the state's decisionmaking process. States do not have to participate under the Coastal Zone Management Act, but all have.

Initially, states receive planning funds to develop a "coastal management program" which consists of three key elements. The first is to establish the boundaries of the coastal zone. This is a difficult task because the coastal zone is defined as the area in which shoreland uses have a direct and significant impact on coastal waters. Hence, to establish the boundaries of the coastal zone is to establish the uses to be managed. The second element is to develop analytical tools for deciding between alternative uses of land or water in the coastal zone. This consists of developing resource inventories and environmental assessment techniques, identifying areas of particular

concern, and dete[illegible] or particular areas in the coastal [illegible] perhaps the most important ele[illegible] the decision-making processes w[illegible] two ways: raising the level of go[illegible] which decisions are made and requiring [illegible] cooperation between levels of government; and, outlining the decision-making process between various decisionmakers and determining criteria and standards they are to use.

Once states have developed a coastal management program they apply to have it approved by the administering office (NOAA in the U.S. Department of Commerce). Once approved, the federal consistency provisions of §307 of the Coastal Zone Management Act come into effect. Under these provisions, all federal projects, federal funding, assistance, and permit activities, must be consistent with the state's coastal management program subject to certain qualifications.[47] The §307 federal consistency provisions may ultimately be the handle on which state and local management programs, exercised under the state's police power, can operate at a par with, or perhaps have key influence over, federal resource and project management programs in a particular state's coastal zone.

The coastal management program is very new and many questions remain unanswered. Most states received initial planning grants in June 1974, and the next few years should see considerable planning activity. However, the Act is not adequately funded and even with states upgrading programs rather than starting new ones, progress may come slowly. CZM must gain acceptance within a state as well. Programs in local planning and zoning, fisheries management, mineral production, and water development must be used in the program and coordination between CZM and these traditional resource management programs must be complete.

CONCLUSION

Previous sections of this paper have reviewed four major fields of regulation and control over land uses which affect estuarine water quality: federal controls over activities affecting wetlands and navigable waters, major federal project review, local and state initiatives in planning and management, and the federal Coastal Zone Management Act. As mentioned in the introduction, this paper does not suggest a major overhaul of the system since for constitutional and political reasons this would be nearly impossible. The main problem is an institutional one, and the concern is how to spend funds over the next five or 10 years to meet this institutional problem.

There are three primary ways to upgrade the current system to meet aspects of the institutional problem: greater support for state coastal management efforts; required coordination between federal programs and between federal and state agencies making similar reviews; and further research and information on technical matters relating to land use controls.

State coastal management initiatives should be given greater support as they are potentially the most important component in the review system. It was developed earlier that at the federal level the U.S. Corps of Engineers, with input from numerous other federal agencies, is the key agency deciding uses of wetlands and estuaries, and that under NEPA, federal agencies involved in major projects must prepare environmental impact statements. At the other end of the scale, private interests and local governments either promote and actively seek, or oppose proposed projects and changes in their areas. Hence, much of the dialogue on reconciling resource management and project proposals with community-focused resource needs is between local and federal interests. Missing in this dialogue, and potentially most useful in resolving problems and seeing a broader perspective, is the state level of government.

It has been described how states have begun to take initiatives in the last few years to develop programs where key areas, or regions, are managed at state level or by local governments subject to state standards and review. Since the coastal management program is specifically designed to upgrade the state's role in the management effort, it should be given greater attention. A number of reasons support this view. 1) Most federal officials and resource users feel that land and water use decisions should be made at the lowest level of government possible. They argue that local units tend to be controlled by political interests and thus argue that the state level should be involved as well. Congress specifically expressed this in the Coastal Zone Management Act by asserting that states in cooperation with local governments should be the focal point for coastal management activities. Also, the current trend in federal administrative matters seems to be in the direction of providing more authority and responsibility at the state and local level.

2) Although the land use bill in Congress failed, and many interpret this as an anti-land use control sentiment in Congress, most people believe that the coastal zone is a different, unique, and highly stressed area. Land use controls are normally accepted at the local and municipal level for urban problems. People

seem ready, indeed, to accept land use controls at a higher level of government where urban fringe and non-urban areas are in the coastal and estuarine zone.

3) The Coastal Zone Management Act is conceived and designed to meet the key coastal and estuarine problems. It combines technical and institutional upgrading as its primary goal, requiring states to address both the question of the manager and the criteria the manager uses for making decisions. The coastal management program is not conceived in isolation from ongoing programs but specifically requires coordination and resolution of differences between state, local, regional, and federal agencies. Further, the policies of the Coastal Management Act seem most suited to resolving tough coastal zone controversies. It is not a mission oriented program but is specifically designed to balance environmental and economic development objectives through analytical techniques and procedures. Finally, it has no vested interest to assert although some have accused it of being a special interest program in its assertion of the importance of the coastal zones over noncoastal areas.

4) Finally, the coastal management program is designed to look at both land and water uses and the interaction between the land and water. It is not limited from a geographical standpoint as is the Environmental Protection Agency ("waters of the United States"), the Corps of Engineers ("navigable waters") or the U.S. Fish and Wildlife Service ("navigable waters"). It can include adjacent uplands as well as water bodies in the definition of the coastal zone. This may facilitate providing a nexus between the community-focused resource planning typical of the local government unit, and the specific resource or project management functions of federal agencies. It also affords an opportunity to consider regional problems from both the community need perspective and the resource/project perspective.

In a recent publication a suggestion was put forward that a program of wetlands control is needed similar to the Federal Water Pollution Control Act of 1972 wherein federal authority would be paramount and specific standards would be promulgated for implementation at the state and local level.[49] This would be an unwise approach. First, it would separate wetlands from associated upland areas thus inhibiting the ability to control the major source of the impacts on wetlands and estuaries. Second, such a wetlands control program would be aimed at enhancement of fish and wildlife resources dependent upon the wetlands resource which, as mentioned before, may not give sufficient consideration to community-focused needs and regional concerns.

There is a difference in philosophy in the approach of the Coastal Zone Management Act and the Federal Water Pollution Control Act. The Coastal Zone Management Act stresses that states should be given maximum flexibility under very general guidelines issued at the federal level; these guidelines relate to the process, not the substance of decisionmaking. The Federal Water Pollution Control Act mandates that federal standards be developed for all emissions and effluents and that states implement these standards. The coastal management approach seems sound in the long run. Where guidelines provide for flexibility and innovation at the state and local level, commitment to the program by state and local officials becomes greater. They are more likely to support its implementation after participating in the formulation of the program.

Further, states differ geographically, socially, and politically. If programs are developed which recognize differences and peculiarities of a state or local area, officials may be more motivated to influence their own people to accept the program than they would be if the program were designed at the federal level. Two states come to mind as examples of these points. California is a leader in the nation in the development of controls over coastal development, perhaps because they have the greatest problems to solve and a highly educated and active citizenry. They will probably progress at a greater speed implementing their own program than would a federal agency implementing a national coastal program in California. On the other hand, Louisiana is a conservative southern state, predominantly rural (with the exception of New Orleans) and with problems of educational, economic, and cultural lag. A great deal of pushing at the federal level will not make a significant difference in Louisiana. Yet, when a local project or program is conceived and executed within the state, the local politicians put a great deal of weight behind it and see that it is developed.

The second major area where the current system of land use controls affecting estuarine water quality can be upgraded is in the *required coordination between certain federal programs and related federal and state agencies granting permits and licenses.* This coordination needs more structuring and funds should be provided for the coordination function. A few examples will illustrate the need and perhaps suggest some remedies. Under the National Pollutant Discharge Elimination System administered by EPA,[50] a certification must be made to the Corps of Engineers that a proposed activity in navigable waters will not adversely affect water quality. Since EPA's primary responsibility is to issue permits to numerous point source emitters, this coordinating mechanism on Corps wetlands permits has been put

at the bottom of the list of priorities; yet, this might be one of the most significant inputs to the Corps of Engineers on wetlands permits. Specific funds should be established to facilitate this review, and the factors to be analyzed should be articulated and described in a manual or workbook.

Another area where better coordination is needed is between state and local wetlands review programs and the Corps of Engineers' permit program. Most states are not equipped or staffed to make adequate input to the Corps on these activities. Federal personnel could be detailed to state offices to assist in providing this input where the primary permit activity is a federal one. Training programs involving state and federal officials are needed to sensitize officials to attitudes and perceptions at the other level of government.

A third area where coordination is badly needed is between state and local efforts at managing coastal resources and other U.S. proprietary functions, especially those associated with offshore oil and gas leasing, coast guard and military bases, and other federal land management functions. There have been frequent instances of differences of management philosophies and management techniques between adjacent federal and state lands in the coastal zone.

Lastly, certain *technical matters* need greater attention if the proper procedures and tools for determining land use and water quality interaction are to be developed. First, the concept of an impact beyond local significance needs to be made operational so it can be used in decisionmaking with some degree of consistency. In the areas of ecology, economics, transportation, and others, tools and techniques are needed for measuring or assessing the extent of impact or significance of a local decision. Second, the cumulative effect of many small, individual decisions affecting coastal land and water use must be determined. Techniques and tools are needed to measure cumulative effects. Third, land use controls have traditionally included government restrictions imposed on private land use in specific districts. Recently, ideas have been discussed called "positive land use controls" involving tax incentives, land trades, transfer of development rights, and so forth.[51] These are designed to offset the inequities resulting from imposition of certain land use controls. Also, they provide greater flexibility in forging new land use control strategies. These three technical matters are not readily "solved," nor are there easy "answers." A better approach in providing assistance to agencies dealing with these matters is to compile and describe experience in this country and abroad, and present that experience in compilations in which the materials are well indexed and abstracted.

FOOTNOTES

[1] U.S. Constitution, Art. I, Sec. 8.

[2] 33 U.S.C. §403

[3] 33 U.S.C. §1251 et. seq.

[4] 42 U.S.C. §1857 et. seq.

[5] 16 U.S.C. §661 et. seq.

[6] 33 U.S.C. §403

[7] 49 U.S.C. §1165g(6)(A). When "Corps" is referred to throughout this paper, "Coast Guard" could be inserted if the project proposed is a bridge or causeway.

[8] 16 U.S.C. §661 et. seq.

[9] The NMFS was originally part of the U.S. Fish and Wildlife Service at the time the Fish and Wildlife Coordination Act was enacted.

[10] "Guidelines for Review of Fish and Wildlife Aspects of Proposals in or Affecting Navigable Waters," 39 Fed. Reg. 29552 (1974).

[11] 430 F. 2d 199 (1970)

[12] Marine Protection, Research and Sanctuaries Act, 33 U.S.C. §1401 et. seq.

[13] 33 U.S.C. §1251 et. seq.

[14] 16 U.S.C. §1451 et. seq.

[15] 33 U.S.C. §1413

[16] 33 U.S.C. §1344

[17] 16 U.S.C. §1452

[18] 33 C.F.R. §209.260

[19] 33 C.F.R. §209.120

[20] 33 C.F.R. §209.120 (g)(3)

[21] 42 U.S.C. §4321 et. seq.

[22] 33 U.S.C. §1341

[23] 33 U.S.C. §1288 and §1313

[24] 38 Fed. Reg. 10834, March 20, 1973

[25] Environmental Protection Agency, "Land Use Implications and Requirements of EPA Programs" (undated draft), 13 p. See also F. Bosselman, D. Fuerer and D. Callies, EPA Authority Affecting Land Use (undated manuscript prepared for Environmental Protection Agency).

[26] 23 U.S.C. §101, et. seq.

[27] 38 Fed. Reg. 24778, Sept. 10, 1973.

[28] 42 U.S.C. 4321, et. seq.

[29] F. Anderson, NEPA in the Courts, Resources for the Future (Baltimore: 1973). Legal and non-legal literature has dealt with NEPA at length in recent years.

[30] 40 C.F.R. §1500

[31] See, e.g., "Housing and Urban Development, Environmental Review Procedures" 24 C.F.R. §58 (39 Fed. Reg. 36554, Oct. 10, 1974); "Department of Transportation Procedures for Considering Environmental Impacts" 39 Fed. Reg. 35234 (Sept. 30, 1974); "USDA Forest Service, Environmental Statement-Guidelines for Preparation" 39 Fed. Reg. 38244 (Oct. 30, 1974).

[32] The authority for these controls arises out of the state's police powers. In most cases, state legislatures have delegated the exercise of the power to local units of government. Courts have been the prime agency determining whether controls exceed constitutional limits by denying the land owner the due process requirement that just compensation be paid for a "taking" of land. See F. Bosselman, D. Callies and J. Banta, The Taking Issue, Council on Environmental Quality (1973).

[33] See, generally, F. Bosselman and D. Callies, The Quiet Revolution in Land Use Control, Council on Environmental Quality (1971).

[34] Wis. Stat. Ann. §59.971 (Supp. 1973).

[35] 7 Del. C. §6801 et. seq.

[36] Wash. Rev. Code Ann. §90.58.010

[37] 3 Pub. Res. Code 27000 et. seq. (Dec. 1973).

[38] 26 Fla. Stat. Ann. §§380.012–380.10

[39] 38 M.R.S.A. §481–488.

[40] Land Use Law, Haw. Rev. Stat. Ch. 205.

[41] Environmental Control Law, 10 Vt. S.A. §§6001–6091 (Supp. 1970).

[42] See Just v. Marinette County, 56 Wis. 2d 7 (1972) upholding the Wisconsin Shorelands Management Act; and, In the Matter of Spring Valley Development by Lakesites, Inc., 300 A 2d 736 (Me. 1973) upholding the Maine Site Location Law, 38 M.R.S.A. §481 et. seq.

[43] See State v. Johnson, 265 A 2d 711 (Me. 1970) construing the Maine Wetlands Act, Me. Rev. Stat. Ann. 12, §4701 et. seq., and San Diego Coast Regional Commission v. See the Sea, Ltd., 109 Cal. Rptr. 377 (1973), limiting the application of the California Coastal Zone Conservation Act, Pub. Resources Code, §27000 et. seq.

[44] Hearings before National Ocean Policy Study, U.S. Senate Committee on Commerce, Santa Monica, Calif., Sept. 27, 28, 1974.

[45] See, Askew v. American Waterway Operators, Inc. 93 S. Ct. 1590 (1973); Hershman and Folkenroth, "Coastal Zone Management and Intergovernmental Coordination," 54 Ore. L. Rev. 13-33 (1975).

[46] 16 U.S.C. §1451. Federal assistance in land use planning activities in the past has been limited primarily to comprehensive planning under the HUD 701 program. An attempt to pass a land use planning bill (H.R. 10294) was recently defeated by the U.S. House of Representatives on June 11, 1974. It may be considerable time before it is again addressed by Congress. This leaves the Coastal Zone Management Act as the only federally approved land use program at this time. Land uses under the law are limited, however, to those having a direct and significant impact on coastal waters.

[47] They are to be consistent "to the maximum extent practicable" in some cases, in other cases certifications of consistency must be filed, and in some cases disputed matters are to be resolved by the Secretary of Commerce in consultation with the Executive Office of the President. The reader is referred to the text of §307.

[48] "The Wetlands: How Well Are They Protected?" Conservation Foundation Letter, Sept. 1974.

[49] Id., at p. 8. The idea is attributed to "some environmentalists" by the publication's editor.

[50] 33 U.S.C. §1251 et. seq.

[51] See, e.g., "Inroads Toward Positive Land Use Management," State of Oregon (Executive Department) 1974; I. Heyman, "Innovative Land Regulation and Comprehensive Planning," Santa Clara Law., 13:185–235, (Winter 1972); D. Listokin, ed., Land Use Controls: Present Problems and Future Reform, Center for Urban Policy Research (Rutgers Univ. 1974).

STRUCTURING THE LEGAL REGULATION OF ESTUARIES

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ABSTRACT

Estuaries are large scale, highly productive physical systems. Regulation and management of estuarine resources is divided among a multitude of agencies at all levels of government. Federal regulation has operated through expanding the mandate of federal agencies to include review of most estuarine resources and consultation with agencies responsible for them. The weakness of this system lies in (1) the unwillingness of the agencies to accept the expanded mandate; (2) the lack of agency expertise to comply with the expanded mandate; (3) the failure to fully staff and fund the consultation mechanism; (4) unequal distribution of resources between the public, private, and governmental bodies. This can be remedied by (a) funding public groups which contribute to agency proceedings; (b) establishing national estuarine laboratories with mixed research and regulatory responsibilities; (c) full funding and staffing of the consultation mechanism.

INTRODUCTION

Estuaries are large scale physical systems of high biological productivity and great complexity dependent on land, freshwater and saltwater components for their natural operation. The estuarine environments support both resident and highly migratory biota, both fish and fowl. The protection of the biota is now a national goal under the Federal Water Pollution Control Act Amendments of 1972.[1] The physical position of estuaries at the confluence of rivers with the ocean has also made them natural foci for the development of commerce and the industrial and urban centers which feed commerce.

The legal mechanisms which control the development and use of the estuarine zones are enormously varied and serve a wide variety of policies: the land use regulations governing shorelands and wetlands which traditionally have been developed and enforced by local government; the technological water pollution control programs affecting particular discharges to the waters; water quality standards governing the water itself; structural schemes of water diversion or of damming, in all of which there is typically a shared federal and state responsibility; and the direct regulation of biota exploitation through fishing and hunting laws developed by the state. Typically, these authorities are divided between different levels of government—federal, state and local—with a number of agencies within each affecting the various elements of the estuarine system.

This paper will focus on the biological production of an estuarine system in order to analyze a typical interaction of legal authorities affecting the estuary's ability to meet its potential for biological production. The emphasis will be on the Hudson estuary and its fishery since legal controversy there has helped to illuminate the practical operation of regulatory authority; the aim is not to deal directly with environmental problems on the Hudson but to put the operation of legal institutions into a concrete context. The paper focuses on the distance between the role theoretically and actually performed by the regulatory agencies and the clash of interests which influences their operation. It suggests methods of structuring the agency–private interest relationship to assure more effective resolution of competing demands on estuarine resources.

SCHEMES OF LEGAL REGULATION

There are at least four models for establishing legal safeguards for the productive capacity of an estuary. First, would be a single agency with regulatory authority to license and control the entire array of human activity affecting the life support system and capacity of the estuary. Logically, the agency would have to have regulatory authority over most use and development of the estuary, its adjacent shoreline, its upstream freshwater sources and the exploitation of its biota both inside and outside the estuarine zone. Second, there is the model of an advisory commission establishing a general plan for protecting the biota. This plan would be considered by each regulatory agency deciding land or water uses, but which would not itself have

direct jurisdiction over the estuarine zone. Third, a requirement could be made of each agency that it must consider and assess the impact of any proposed action on the productive capacity of the estuary and take necessary steps to protect or minimize the damage to the resources. Fourth, a single agency could be responsible for protecting the productive capacity of the estuary. The authority of such an agency could be either advisory or include the power to reject the proposals of other agencies. Under each model, of course, the objective can be altered to assure the biological productivity of the estuary either greater or less weight in the decisionmaking process.

Examples of the first two models can be found in the Delaware River Basin Commission[2] and the New England River Basin Commission,[3] but they have not been the primary force in recent years affecting the regulation of the estuaries. For instance, the proposal for a Chesapeake Bay Commission in Maryland to control the use and development of Maryland's side of the bay failed of enactment.[4]

In recent years, legislation has moved in two distinctive directions. First, the mandates of federal and, in some cases, state agencies have been widened beyond their primary missions by requirements to consider and weigh the environmental impacts of the agency's activities. The National Environmental Policy Act (NEPA) is the most obvious example of such a mandate-widening statute which requires a fresh look and a new balance from agencies with traditionally narrow mandates.[5] Other examples may be readily found. The courts have reasserted the broad mandate of the Federal Power Commission, so that that agency must look at a broad spectrum of concerns in licensing hydroelectric projects.[6] The land use planning sections of the 1974 Housing and Community Development Act have been expanded to require recipients of planning grants from the Department of Housing and Urban Development to consider environmental issues.[7]

Second, a number of statutes have been enacted which look at particular environmental media or physical areas and require a new, environmentally-protective analysis in the decision process which governs their use and development. The Federal Water Pollution Control Act Amendments of 1972,[8] state wetland protective statutes,[9] and the Coastal Zone Management Act[10] are examples of this approach. These legal structures do not directly focus on the estuarine zone, but they operate within it to produce an overlay of review and analysis which takes into account, to at least some extent, the productivity of estuaries. Most of these statutes as well as others already on the books require resource planning or protection which, if followed through in action, will have long-term impacts on the estuarine productivity.

These new statutory initiatives take their place in a context where some agencies with focused resource responsibilities are also required to consult with state or federal agencies which directly engage in, or license private parties to engage in, the alteration of environmental conditions. These referral and consultation requirements are established to protect the resource. In the context of protecting estuarine biota, the most important of these statutes is the Fish and Wildlife Coordination Act[11] which requires consultation on wildlife preservation with the Fish and Wildlife Service of the Department of the Interior and National Oceanic and Atmospheric Administration of the Department of Commerce. Obviously, NEPA has the same type of consultation requirement.

These legal regulations work as a composite of the third and fourth models set out above. Many state and federal agencies have been given expanded mandates both in land and water resource planning, and in controlling sources of pollution or other factors affecting estuarine productivity. These agencies are required to consult particular agencies assigned to protect certain values in estuarine development.

This legal structure and management model are likely to be the basic pattern for some time to come. It is therefore worthwhile to identify the salient aspects of the model which are essential for its proper operation and analyze whether thay have operated effectively and, if not, suggest how they can be improved. This is done in the context of the Hudson and its fishery in order to give the general point concrete focus. The operating records of the Federal Water Pollution Control Act Amendments of 1972 and the Coastal Zone Management Act are too brief to allow review of their effectiveness in addressing the issue in this context. NEPA and the state wetlands statutes now have longer histories which make them useful for analysis. The emphasis here will be largely on NEPA for a number of reasons: it is a federal statute and thus more relevant to Congress's concerns; it is central to an analysis of both the expanded mandate and referral and consultation mechanisms; the principal restraints on state wetland legislation stem from the constitutional requirements of the Fifth Amendment that private property not be taken for public use without just compensation—thus these restraints cannot be directly remedied by legislation.

THE CYCLE OF THE HUDSON FISHERY

The Hudson is a tidal estuary from New York City to Troy, north of Albany. The line of the salt front varies with the freshwater discharge but is generally 40–65 miles upstream from the Battery. Gross pollution problems have been concentrated at New York City and Albany and the central reach of the estuary has historically supported a highly productive fishery.

Henry Hudson reported the river teeming with "the finest fish among which was the shad and many kinds scarcely less delicious . . . there were plenty of sturgeon which the Christians do not make use of, but the Indians eat them greedily . . . herring were in myriads."[12] In the early 19th century, the sturgeon were so abundant that they were known as "Albany beef" and there was a flourishing caviar industry.[13] Today, the striped bass and the shad are the most important sport and commercial fish. There is a wide diversity in the array of migratory and resident fishes in the river, alewife, blueback herring, white perch, bay anchovy, and tomcod, among others.[14]

The life cycle of the anadromous, estuarine-dependent fish is significant to understanding the variety of places at which uses and development can affect the capacity of the river's productive resources. The striped bass may be taken as an example of the life cycle of the anadromous fish for these purposes. In the spring, the adult stripers come upstream from the sea and the over-wintering areas in the Hudson Estuary into the estuary's freshwater section. The extent of the upstream migration depends on the water temperature and on the location of the salt front. In most years, the bulk of the eggs are spawned between 50 and 100 miles upstream from the Battery during May and early June.

The striped bass eggs are released free into the water and drift with the flow of the currents. During the first six to eight weeks of life, the striped bass pass through egg, yolk-sac larval, and larval stages and enter the early juvenile stage. During this period, the organisms gain mobility but their gross movements are determined by the hydrology of the tides, currents, and saltwedge. At the end of the planktonic stage, the young bass begin to move into shallow water, either along the shore or on shoals. These shallow areas are the nursery habitat of the fish during the first year of life.[15]

The young striped bass spend their first winter in the Hudson and then start to move into the sheltered coastal waters. With increasing age, the fish make longer migrations into more open waters. There is no question that the Hudson makes a major contribution to the coastal stock of striped bass in the waters of the New York Bight and Long Island Sound and perhaps is a major source for the fish along the entire south shore of Long Island and in New England waters.[16]

It is obviously possible to affect the estuary's production of striped bass or other biota, both in the short and the long run, by altering the conditions which foster continuing high production and control survival during each phase of the fish's life cycle. In the Hudson many such intrusions have taken place. Historically, there has been intrusion on the adult population through the fishery catch, so that by the mid-1930's, when a 16-inch size limit was imposed, the stock was at much lower levels than it is presently.[17] There has been intrusion on the migratory, returning spawners through catching in nets set in the Hudson for the taking of shad, which also take striped bass.[18] Recently, there has been intrusion on the early life stages of eggs and larvae by entrainment of the fish through the cooling systems of power plants on the Hudson, and there has been intrusion on the juvenile stage through impingement of those fish on the screens of power plant intakes on the river.[19]

Obviously, other equally serious intrusions are possible. For instance, the striped bass population of the Delaware River has been virtually decimated due to gross pollution, mainly oxygen reduction, in the crucial reach around Philadelphia.[20] The central Hudson from the Tappan Zee to Coxsackie is the crucial area for the spawning and nursery habitat and has been relatively clean, but if industrial and municipal pollution on the scale present at New York City or in the Albany pool were to occur here, the Hudson-supported striped bass population could be severely reduced. On the Sacramento-San Joaquin system, the population of striped bass has been halved, apparently by the effect of water withdrawal for irrigation purposes which also withdraws the eggs and larvae from the river.[21] Were the proposal to withdraw freshwater for municipal use from the Hudson at Hyde Park to come to fruition, a similar effect would become a real possibility on the Hudson.[22] If dams were to be constructed on the river, as has happened on the Susquehanna, there would be a major disruption of the spawning run and a consequent effect on the juvenile and adult fish population. Extensive filling of the remaining shallow areas of the Hudson, particularly in the Tappan Zee and Haverstraw Bay, would deprive the fish of its juvenile habitat.

This catalogue indicates the broad range of activities that have to come within legal control if the basic productivity of an estuary is to be protected and preserved and even if development and exploitation of the resource are to be properly analyzed and managed.

THE EXPANDED MANDATE SCHEME AND THE HUDSON EXPERIENCE

Over the last 10 years, there has been continuing controversy in the Hudson estuary over the effects of proposed developments, particularly power plants, on the fishery of the river. This controversy illuminates development under statutes providing for the weighing of competing interests by administrative agencies under expanded mandates which include consideration of estuarine productivity. It also allows analysis of the operation of the referral and consultation mechanisms.

The fishery issue was first raised on the Hudson in the early 1960's in connection with Consolidated Edison Company's application to the Federal Power Commission (FPC) for a license to build and operate the Storm King pumped storage project at Cornwall about 56 miles upstream from the Battery. Storm King would pump water from the Hudson to a reservoir from which it would be released to produce hydroelectric power.[23] The water withdrawals required to run the plant would be of great magnitude—averaging 15–18,000 cubic ft/sec over an 8-hour pumping period each day.[24] After a cursory review, the FPC granted Con Edison the license.

The license was challenged by a citizens' group and in Scenic Hudson Preservation Conference v. FPC,[25] the Second Circuit Court of Appeals ordered the FPC to reconsider the issuance of the license. The court decision required the FPC to allow citizens' groups to present their evidence and arguments to the Commission and laid on the Commission the affirmative duty of building a full factual record on which to base a reasoned decision. The extent of the record was determined by the broad mandate of the Federal Power Act, which required the FPC to determine that the project "will be best adapted to a comprehensive plan for improving a waterway . . . for the use or benefit of interstate or foreign commerce, for the improvement and utilization of waterpower development, and for other beneficial public uses, including recreational purposes."[26]

The court's interpretation of the statute made it the functional equivalent of NEPA's expanded mandate requiring that the analysis by the FPC look at the broad range of public interests affected by the project and also consider possible alternatives. One of the issues singled out for consideration by the FPC on remand was the entire fishery issue, particularly the effect of Storm King's operation on the striped bass and the shad. Thus, because of the 1965 decision in Scenic Hudson, there began to function in the Hudson estuary a NEPA type of expanded review, five years before that statute was passed.

The FPC delegated the fishery investigation responsibility to the Hudson River Policy Committee, a group formed for the purpose and made up of representatives of the U.S. Bureau of Sports Fisheries and Wildlife, the old Bureau of Commercial Fisheries (now the National Marine Fisheries Service), and the Fish and Game Departments of New York and New Jersey, with an observer from Connecticut.[27] Most members of the policy committee were not professional experts on the Hudson fishery and so they in turn oversaw the work of hired consultants.[28] The results of a 3-year research program were published as the Hudson River Fisheries Investigation 1965–1968 (HRFI).

The analysis undertaken in HRFI focused primarily on the striped bass population of the Hudson. The final report concluded that the project would not have a significant effect on the striped bass fishery, since it would take at most 4 percent of the striped bass eggs and larvae from the river.[29] The investigation was completed and the report published after the remanded hearings before the FPC were concluded, so that the Power Commission took official notice of and relied upon the HRFI conclusions but never exposed them to critical examination in a hearing. The necessity of looking at the Storm King withdrawals in the context of withdrawals by other plants on the Hudson is mentioned in the HRFI conclusions, but no analysis of total withdrawals on the river was undertaken. This would, of course, appropriately come within the ambit of the FPC's responsibility to see that the project was in keeping with a comprehensive plan for development of the waterway.

The HRFI report provided an essential data base on the Hudson fishery, particularly the striped bass. But it was not an exhaustive review of the entire life cycle of the fish. HRFI provides a thorough examination of the distribution and abundance of the eggs, larvae, and juvenile stripers in 1966 and 1967 throughout the Hudson with a more detailed study around the plant site in 1968. There is no discussion or analysis of the relation of the Hudson-spawned fish to the coastal stock, nor is there any attempt to judge the productive capacity of the estuary against its actual production. In other words, it does not address the general management

of the fishery. Most importantly, while the collection and presentation of data in the report was generally considered to be of high quality, later analyses showed that the calculations which related the plant's operation to the withdrawal of organisms from the river were seriously flawed. The analysis underlying these calculations was not consistent; a dynamic analysis relating the rate of withdrawal to the river flow past the plant compared the plant's withdrawal rate to the tidal flow and not to the net downstream flow; in the static analysis a daily withdrawal rate of absolute numbers of organisms was presented but the withdrawals were not cumulated over the season.

It was some years before these facts became clearly known to the interested public. They were not apparent at the time when the court of appeals reviewed the construction and operating license which the FPC issued to the company in 1970. That license was approved in the second Scenic Hudson case.[20] The analysis of the failings of the HRFI report did not come in an FPC proceeding but rather in a NEPA proceeding before the Atomic Energy Commission (AEC).

When NEPA became law in 1970, serious plans or construction were going forward at four power plants in the central reach of the Hudson which would affect the estuary's fishery—the Indian Point 2 and 3 nuclear units were in construction, and the Bowline and Roseton fossil fuel units were about to begin construction. Starting in 1972, hearings were held under the NEPA mandate before an Atomic Energy Commission licensing board on the Indian Point 2 plant, which is 13 miles downstream from Storm King and designed to withdraw less water from the estuary—800,000 gallons per minute. Here, from the beginning, the major environmental issue was the effect of plant operation on the biota and the biological productivity of the estuary, particularly through the entrainment of eggs and larvae through the plant.

The analysis of the Indian Point plant, conducted by AEC experts from the Oak Ridge National Laboratory, built on the foundations of the HRFI report, and thus essentially limited its analysis to the striped bass. It included a hydrological computer model to power the organisms through the estuary under various freshwater flows and added an analysis of the relation of the Hudson spawning grounds to the coastal stock of striped bass and at least a basic analysis relating the Hudson's productive capacity to its actual production. On this basis, the Oak Ridge staff concluded that the Indian Point 1 and 2 plants would take between 30 and 50 percent of the annual production of striped bass in the Hudson which would be reflected in a similar decline in the size of that year class when they became adults.[21] The Hudson River Fishermen's Association (HRFA), a group of sport and commercial fishermen and conservationists, participated in the hearing as intervenors, providing a non-computer model analysis which reached essentially the same conclusions as the Oak Ridge staff.

Con Edison opposed this interpretation of the data, putting forward its own analysis of the HRFI material in a different analytical model. The predicted effect on the Hudson striped bass production was small, in the 2–6 percent range. A sensitivity analysis of the model's operation showed that the major factor in the differing results was the inclusion by Con Edison's experts of a compensating mechanism in the model which was density dependent and thus increased the survival of the remaining population as the plants reduced the population. The company further denied the major contribution to the coastal stock of New York and New England which was put forward by the Oak Ridge staff. More importantly, on the grounds that there was not enough data to analyze the impact of the plant, the company launched a major research program to determine, by a study to be conducted before and after operation began, what the effect of the plant's operation on the fishery would be.

At the close of the proceeding in 1974, the AEC, while not accepting all the analysis of the Oak Ridge staff and HRFA, agreed with their ultimate conclusion and required Con Edison to install a closed-cycle cooling system at the Indian Point plant but also gave the company a chance to ask for an amendment of the license terms if the research program led it to believe that such a change was justified.[22]

During the same period, the Army Corps of Engineers approved construction permits for the two fossil fuel plants on the Hudson. In March 1970, the Corps approved the construction permit for the 1200 megawatt Roseton plant owned jointly by Central Hudson Gas and Electric, Con Edison, and Niagara Mohawk. The plant would withdraw 650,000 gals/min from the river at approximately river mile 65. The Corps did not undertake any NEPA impact study on the plant. In 1971, the Corps allowed work to go forward on the construction of the Bowline plant, another 1200 megawatt plant withdrawing 750,000 gals/min from the Hudson and set back from the river on Bowline Pond at approximately river mile 37, without the completion of a NEPA impact statement. That plant is owned jointly by Orange and Rockland Utilities and Con Edison. Both plants are within the central reach of the Hudson, and it is self-evident that they present

the same fishery issues as does Storm King or Indian Point. The Corps circulated a draft impact statement on Bowline in 1971, but its analysis of the impact on the fishery was so limited and cursory that one was hard put to realize that the plant was to operate on the same river with Indian Point and Storm King. In December 1972, two suits were filed against the Corps of Engineers by HRFA over the Corps' failure to carry out a NEPA analysis on either of these plants before construction began.[33] Settlement agreements have been reached in both cases; the Corps has agreed to undertake a NEPA impact study at Bowline and to analyze the Roseton plant in conjunction with the Bowline statement.[34] At the same time, the Corps has stated in the consent decree that it does not have the manpower and expertise to analyze the fishery issues at stake and therefore the utilities, as part of the settlement, have provided the Corps with $75,000 to hire an outside consultant.[35]

Just as the analysis conducted for Storm King laid the foundation for the expanded analysis at Indian Point, so the work done at Indian Point indicated the flaws of the Storm King analysis and led to a request for further consideration of the fishery issue in relation to Storm King. On the basis of both direct analysis of the HRFI calculations and an estimate of the withdrawal of striped bass eggs and larvae by Storm King made with the model developed to analyze Indian Point, estimates were made by Oak Ridge and Brookhaven National Laboratory personnel and HRFA's expert that 30–40 percent of the eggs and larvae in the river would be withdrawn annually by the Storm King plant. These analyses were presented to the FPC in early 1973 with a petition for further hearings on the impact of the plant on the fishery. The FPC refused to hold hearings on the data and analysis, and an appeal was taken to the Second Circuit Court of Appeals which in May 1974 remanded the fishery issue back to the power commission for immediate hearings.[36]

The remanded hearings are now underway, but have quickly passed beyond the analytical failings of the HRFI report. The new research effort that Con Edison launched in response to the Indian Point proceedings in 1972, and as a further preoperation study of Storm King, is now producing data, and this material is now being reviewed before the FPC in the Storm King proceeding. Thus, the major issues addressed at Indian Point are being worked over again, but with a major added round of factual data as well as further refinements of the computer models.

Further data collection is underway from the utilities and further agency review of the material is to be expected. It is likely that EPA will have to work through the data in response to requests for variances from the closed-cycle cooling requirements now imposed at Indian Point, Bowline, and Roseton. Further hearings on Indian Point 2 and 3 before the AEC's successor agency, the Nuclear Regulatory Commission, are likely to be requested by the company on the basis of new evidence.

THE OPERATION OF THE EXPANDED MANDATE AND THE CONSULTATION AND REFERRAL SCHEME

Agency Unwillingness To Accept the Expanded Mandate

None of the three agencies involved in the expanded mandate reviews under the Federal Power Act or NEPA willingly undertook to effectively fulfill its expanded mandate on the issue of the estuarine fishery. The Court of Appeals has twice sent the Storm King case back to the FPC for full and proper investigation of the fishery. The AEC undertook the analysis of the fishery at Indian Point only after it was ordered to do so by the Court of Appeals for the District of Columbia Circuit in Calvert Cliffs' Coordinating Committee v. AEC.[37] The Corps of Engineers undertook the review of Roseton and Bowline only in settlement of suits brought by HRFA.

It may be argued that this is only the difficulty of initial compliance with broad mandates. I believe the trouble lies deeper. The FPC had had its mandate for many years before the 1965 decision. Even EPA which should be most willing to take a broad look at environmental issues has shown itself unwilling to comply with the Act in areas such as granting funds for waste treatment facility construction.[38] Numerous federal agencies have attempted to delegate their NEPA responsibilities to others, frequently those in state government.[39]

The recipients of federal grants or licenses have little interest in pressing the government to comply fully with the terms of the expanded mandate. This has meant that the only effective force for assuring full compliance has been public groups who would be protected by operation of the mandate and who are willing to exert pressure on the agency. I see no reason to think that this will not continue to be true.

The Lack of Agency Expertise To Comply With Expanded Mandate

None of the three agencies reviewed here, the FPC, the AEC, or the Corps of Engineers, had

within its line staff the expertise to analyze properly the estuarine biological system. This may be less frequently true for small projects, say the filling of an acre of wetland for which a Corps permit is necessary, but is likely to be the normal circumstance for many large projects producing significant and widespread effects across complex estuarine systems.

In each of the cases reviewed, the agency turned to groups outside its own line staff to analyze the problem presented to it. The FPC turned to the Hudson River Policy Committee, which was drawn from the federal and state agencies with responsibility for fishery matters. The Corps of Engineers turned to an outside private consultant to review the impact of the two fossil fuel plants, and further built consultation with the Interior Department into the license terms for the two plants, stating that the Secretary of the Army would rely on the Secretary of the Interior to recommend measures which should be taken to protect the fish and wildlife of the Hudson River.[40] The AEC turned to the Oak Ridge National Laboratory for its analysis of the plant's impact on the river. Oak Ridge was, of course, part of the AEC, but not under the same regime as the regulatory staff, so that the regulatory branch of the Commission had to apply to the research arm for this NEPA work.[41]

It is evident that there is no internal repository of analytic strength or developed policy to which most agencies with an expanded mandate can turn. This is made clear by the fact that each agency turned to different sources to obtain expertise. From the product produced in each case, it is equally evident that there are highly variable levels of ability among the experts to whom the agencies turned.

This situation makes the results of operation under the expanded mandate very uneven. Another result is that when opposing private groups such as Con Edison and HRFA have litigated the same essential issues more than once, they tend to be more informed than the experts to whom the government agency turns, so that the "experts" are being educated by the partisans. To a certain extent, such education is good and proper, but the agency should have within its own organization or easily accessible to it impartial sources of expertise to which it can turn for aid.

Realistically, no agency is likely to have the full range of expertise inhouse that is needed for full and effective estuarine review. It is therefore essential that institutions modeled on the national laboratories be established with a special estuarine mandate to provide to relevant agencies the expertise needed for these analyses. Such institutions should be able to retain high quality personnel by offering a mix of research opportunities with analytic and semi-regulatory responsibilities. Only this mechanism will provide the agencies with expertise necessary for the effective discharge of their responsibilities.

Failure of the Consultation and Referral Mechanism

In the licensing proceedings reviewed, both NEPA and the Fish and Wildlife Coordination Act required the agency granting the license to consult with other agencies and groups with relevant expertise and jurisdiction. NEPA requires consultation with a wide spectrum of groups and interests. The Fish and Wildlife Coordination Act requires consultation with the Fish and Wildlife Service in the Department of the Interior, the National Oceanic and Atmospheric Administration in the Department of Commerce, and state agencies concerned with wildlife protection. The review here will focus on these federal and state agencies with fish and wildlife responsibilities.

Before the FPC's 1970 licensing of Storm King, all these agencies played an important role through their participation on the Hudson River Policy Committee, but in the remanded hearings in 1974, that position has shifted. The Interior Department is participating in the hearings and there is a task group of Interior and Commerce experts working on an analysis of the plant's possible impact. But the successor to the Hudson River Policy Committee, the Hudson River Fish and Wildlife Management Cooperative, has publicly declined to take a significant part in the hearings.[42] This is so despite the fact that the cooperative is made up of representatives of the Division of Fish and Wildlife and the Division of Marine and Coastal Resources in the New York Department of Environmental Conservation, the New Jersey Division of Fish, Game and Shellfisheries, the U.S. Bureau of Sport Fisheries and Wildlife, and the National Marine Fisheries Service, and has as its stated objectives to:

1. Coordinate evaluation of environmental impacts on fish and wildlife resources of the estuary and formulate appropriate response.
2. Develop a comprehensive fish and wildlife management plan for species of interstate significance.
3. Encourage implementation of the comprehensive plan by the agencies with primary responsibility.[43]

Thus the group which on paper should provide major guidance on fishery issues has chosen not to

do so in the context of proceedings whose outcome may affect the fishery.

In the AEC and Corps of Engineers proceeding, the Interior Department submitted letters commenting on both impact statements.[44] The Corps' initial draft impact statement on Bowline in 1971 gave no indication that the plant could have serious impact on the fishery; Interior's letter did not disagree with that position.[45] The AEC's draft statement on Indian Point indicated the possibility of substantial damage to the fishery, though not the level of impact predicted in the final statement. Interior wrote the AEC a strenuous letter advocating the use of a closed-cycle cooling system.[46] The Department of Commerce did not submit anything substantial in response to either impact statement.[47]

Left to themselves, Interior and Commerce have largely reacted to what the other agencies have put before them. Where the work of the referring agency has been thorough and competent, the response under the Fish and Wildlife Coordination Act has been pointed and helpful. Where the referring agency's work has been second rate, the Coordination Act response is little better except in those cases which are the focus of public attention; then, as in the 1974 Storm King hearings, a special effort is made by the departments.

This is not an impressive record, but it is only fair to point out that the agencies are now staffed and funded to about one-half of what they and General Accounting Office believe is necessary for the effective operation of the Coordination Act.[48] This appears to be the fault of the executive branch in not requesting sufficient funds from Congress.[49] We will not really know whether this system can work properly unless it is adequately staffed and funded.

In addition to sufficient funding, Interior and Commerce will need an organizational format with an ongoing comprehensive view of estuarine systems and their wildlife. I can see no basic reason why this obvious organizational method of dealing with the Coordination Act responsibilities should not be achieved, but it has not yet been done.[50]

The State of New York has primary responsibility for the Hudson fishery, but it has not demonstrated the ability to develop its own articulated position on the fishery or to critique fully the positions put forward by others.[50A] The Department of Environmental Conservation (DEC) has primary responsibility for fishery management, but it has not produced a basic fishery management policy for the estuary. The state has the typical array of limitations on catch sizes, nets, meshs, and open seasons;[51] but these regulations are not drawn together into a policy which reflects any clear opinion on the life cycle or population dynamics of the striped bass or most of the rest of the estuarine fishery. This may be in part the product of history, since in New York in the past, the emphasis has been on the cold water fishery and the marine commercial fishery with little attention focused on the estuarine zone.[52] The net result is that the DEC has taken a back seat in determining the course of development which can affect the fishery. The department was represented on the Hudson River Policy Committee in the 1970 licensing of the Storm King plant, but as part of the Hudson River Management Cooperative, it has declined to take part in the analysis of fishery issues in the present remand. Before the AEC, the DEC was represented through the New York State Atomic Energy Council, but neither presented evidence nor took a position on the fishery issues before the licensing board. Its role before the Army Corps of Engineers has been equally passive.[53]

Unfortunately, New York's record of fishery management is reasonably typical of the performance of other states[54] and perhaps the fishery management profession generally.[55] It would not be a wise policy for the Congress to rely on the states to develop sound policies for the protection of estuarine productivity. These circumstances underscore the importance of full staffing and funding of Interior and Commerce's fish and wildlife agencies and the provision of expert assistance to the agencies with the expanded mandates.

Unequal Distribution of Resources

At least in the case of large projects, the resources brought to bear in licensing proceedings are very unequally distributed. The industrial or developmental interests are willing and able to devote hundreds of thousands, even millions, of dollars to procuring a license or permit to exploit estuarine resources. Citizens' groups have budgets which at best run in the tens of thousands and are dependent on pro bono or reduced fee help from lawyers and scientists. The governmental agencies expend sums which lie somewhere between industry and the private groups, but all too often closer to the private groups.

Con Edison is now spending approximately $3 million a year over a 5-year period on biological research alone on the Hudson.[56] Other utilities are contributing their share, and these sums do not include attorneys' fees or the other costs of applying for and obtaining a license. Congressional documents show that utilities now budget $500,000 to $1,000,000 for major nuclear licensings.[57]

Next to these massive sums, government expenditures appear puny indeed. The present Fish and Wildlife Service budget for all Coordination Act programs for the entire country is $7.5 million.[58] The Corps of Engineers was willing to pay consultants only $75,000 for a NEPA impact analysis to cover two fossil fuel plants on the Hudson.[59] Since applicants for permits take on most of the primary research, some greater expenditure on their part is to be expected. But these figures indicate utterly disproportionate spending.

The resources of citizens' groups representing public interests are even more scanty. The average intervention in an AEC proceeding costs $50–60,000.[60] Few groups can raise sums of this magnitude. On the Hudson, groups like HRFA and Scenic Hudson have existed on tiny annual budgets with the help of pro bono legal and scientific assistance.

Congress has increasingly encouraged citizen participation in environmental enforcement by, for instance, providing citizen suit provisions and allowing the payment of reasonable attorney and expert witness fees in such suits under the Clean Air Act and the Federal Water Pollution Control Act Amendments of 1972.[61] To be effective, this policy should extend more widely to proceedings before administrative agencies as well. It is there that facts on environmental issues are increasingly tried out and thus where the major expenses of litigation occur as well as where the terms of discretionary decisions are hammered out. It has generally been conceded that if our system of justice is to operate effectively, there must be a rough equality of resources on both sides of an argument. We must move closer to seeing that such equality is the fact as well as the ideal.

DISCUSSION AND RECOMMENDATIONS

The legal regulation of estuaries operates primarily through administrative agencies which have direct jurisdiction over part but not all of the estuarine system or its resources. The federal agencies typically operate through an expanded mandate requiring them to consider all the resources of the estuary and the effects of their actions on the entire system. Coupled to this expanded mandate is a system of consultation and referral putting particular emphasis on expert advice and recommendations from agencies with expertise and responsibilities which are focused on particular resources in the estuarine system such as fish and wildlife.

The record of effective regulation under this system has not been good for four primary institutional reasons: (1) the agencies are reluctant to fulfill their expanded mandate and frequently do so only under pressure from the public; (2) the agencies frequently do not possess the expertise to fulfill the mandate and rarely have an effective and impartial government source to which to turn for aid; (3) the federal referral agencies are understaffed and underfunded and thus are incapable of effectively dispatching their responsibilities, and the state agencies have a poor record of performance which does not hold much promise for future improvement; and (4) the resources brought to the decisionmaking process are overwhelming favorable to the private industrial and developmental interests and thus they tend to dominate both the governmental and public interest input to the process.

To make the system work effectively, there must be an evening of resources, so that the major interests—governmental, industrial, and public—are properly balanced. This should be achieved by taking three measures:

1. Within the discretion of the agency, groups representing public interests should be able to obtain reasonable attorney and expert witness fees in agency proceedings where they have contributed to the development and resolution of the issues before the agency. A model for such a provision exists in Title V of the Senate version of the Energy Research and Development Act of 1974[62] and should be adopted for all federal acts dealing with estuarine development and regulation. This will answer, in part, problems 1 and 4 set out above.

2. Congress should establish three or four National Estuarine Laboratories. Effective research and analytical support must be made available to the regulatory agencies on a continuing basis from institutions which develop expertise on entire estuarine systems and are required to present positions on proposed projects. The regulatory agencies cannot be entirely dependent on the presentation and analysis of facts by outside parties and what they need from within the government is much more than ad hoc consultation on particular projects under pressure for quick analysis. There must be a form of advocacy laboratory which engages in broad analysis and research so that it is readily familiar with major estuarine systems and produces an articulated program for protecting the estuary's productive capacity. Such a program would be able to put the individual and cumulative impacts of development in context from the viewpoint of the entire estuarine system and thus overcome some of the disadvantage of dispersed governmental authority. This would, in part, answer problems 1, 2, and 4 set out above.

3. The federal referral agencies under the consulation mechanism must be fully funded and staffed, and organized so that they maintain ongoing knowledge and expertise on entire estuarine systems. The General Accounting Office has already reported this need to Congress in the case of the Fish and Wildlife Coordination Act, and it is recognized as essential by the agencies affected. Action must be taken to put it into effect. This is the only course of action by which we will be able to test whether this system is or is not effective in providing protection to estuarine resources and productivity. This would, in part, answer problems 3 and 4 set out above.

FOOTNOTES

[1] 33 U.S.C. §1251(a).

[2] Delaware River Basin Compact, N.Y. Environmental Conservation Law §21-0701, et. seq. See Ackerman & Sawyer, "Uncertain Search for Environmental Policy: Scientific Factfinding and Decisionmaking along the Delaware River," 120 U. Pa. L. Rev. 419 (1972).

[3] 42 U.S.C. §1962(b), Executive Order No. 1137, 32 Fed. Reg. 12903 (1967) as amended.

[4] Power, "Chesapeake Bay in Legal Perspective," U.S. Department of the Interior, Federal Water Pollution Control Administration, Estuarine Pollution Study Series—1 (1970); personal communication with author.

[5] 42 U.S.C. §4321 et. seq. The terms of the National Environmental Policy Act are so well known that extensive description seems unnecessary, but a brief outline of the expanded mandate aspect may be useful. The Act requires that each federal agency in considering any project which would significantly affect the quality of the human environment and which the agency itself would undertake or which it can license or permit a private party to undertake must prepare a full statement on the impact of the project on the environment. 42 U.S.C. §4332. The Act instructs federal agencies, inter alia, to:

> preserve important historic, cultural, and natural aspects of our natural heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice; [and] . . . achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities. 42 U.S.C. §4321(b).

This is to be achieved "consistent with other essential considerations of national policy." Id.

While making environmental protection a part of the mandate of each agency, the Act provides for a system of careful analysis rather than a particularized policy of protection:

> Thus the general substantive policy of the Act is a flexible one. It leaves room for a reasonable exercise of discretion and may not require particular results in particular problematic instances. . . . NEPA mandates a rather finely tuned and 'systematic' balancing analysis in each instance. *Calvert Cliffs' Coordinating Committee v. AEC*, 449 F.2d 1109, 1113 (D.C. Cir. 1971).

[6] Scenic Hudson Preservation Conference v. Federal Power Commission, 354 F.2d 608 (2d Cir. 1965), cert. denied, 384 U.S. 941 (1966).

[7] 40 U.S.C. §461 as amended by the Housing and Community Development Act of 1974, Sec. 401(b), (k), 88 Stat. 687–689.

[8] 33 U.S.C. §1251 et seq.

[9] 12 Me. Rev. Stat. Ann. tit. 12 §§4701–4709 (Rev. 1964, Supp. 1972); 38 Me. Rev. Stat. Ann. §§481–488 (Supp. 1972); N.H. Rev. Stat. Ann. §483-A (Supp. 1971); Mass. Gen. Stat. Ch. 130, §27a (Supp. 1971); R.I. Gen. Laws Ann. §11-46-1.1 (Supp. 1971); Conn. Gen. Stat. §§22a–28 to 22a–34; N.Y. ECL. §§25-0101 et seq. (McKinney 1973); N.J. Stat. Ann. §13:9A-1 to -10 (Supp. 1971); 7 Del. Code Ann. Ch. 70, §§7001 et seq.; Md. Ann. Code Art. 66C, §§718-31 (Supp. 1970); Va. Code Ann. §§62.1-13.1 to 13.20 (Supp. 1972); N.C. Gen. Stat. §113.229 et seq., (Supp. 1971); S.C. Code Ann. §§70-13 to -42 (Supp. 1973); Ga. Code Ann. §§45-136-147 (Supp. 1972); Fla. Stat. Ann. §§253.122–123 (Supp. 1972).

[10] 16 U.S.C. §1451 et seq.

[11] 16 U.S.C. §661 et seq.

[12] Hunt, A Historical Sketch of the Town of Clermont, Hudson (1928).

[13] State of New York Conservation Department, "A Biological Survey of the Lower Hudson Watershed," 15 (1937).

[14] Id.; Hudson River Policy Committee, "Hudson River Fisheries Investigation 1965–1968" (undated) (hereafter HRFI).

[15] U.S. Atomic Energy Commission, Directorate of Licensing, Final Environmental Statement, Indian Point Nuclear Generating Plant Unit No. 2, Sept. 1972 at V-40 (hereafter "IP2 FES"); Clark, "Effects of Indian Point Units 1 and 2 on Hudson River Aquatic Life," October 30, 1972 in transcript of In re Consolidated Edison Company of New York, Inc. (Indian Point 2) AEC Docket 50-247, following Tr. 6276, at 5-6 (hereafter "IPS Tr. at ——").

[16] 1 IP2 FES XII-29 to XII-35; Raney, "The Striped Bass, *Morone saxatilis*, of the Atlantic Coast of the United States with Particular Reference to the Population Found in the Hudson River," October 30, 1972, IP2 Tr. following 6254.

[17] 1 IP2 FES V-56.

[18] Testimony of C. Phillip Goodyear, IP2 Tr. at 9068–9071.

[19] In re: Consolidated Edison Company of New York, Inc. (Indian Point 2) RAI-73-9 751 (1973).

[20] Chittenden, "Status of the Striped Bass, *Morone saxatilis*, in the Delaware River," 12 Ches. Sci 131-36 (1971); Goodyear, "Origin of the Striped Bass Stock of the Middle Atlantic Coast," March 1, 1973, IP2 Tr. following 9858.

[21] Turner & Chadwick, "Distribution and Abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary," 101 Trans. Am. Fish. Soc. 442–452 (1972); Clark, "Effects of Indian Point" at 54, IP2 Tr. following 6276.

[22] Temporary State Commission on the Water Supply Needs of Southeastern New York, "Water for Tomorrow," (1973). See N.Y. Times, March 15, 1975 at 29, col. 8.

[23] F.P.C. Opinion No. 584 (August 19, 1970).

[24] HRFI at 40; Affidavit of John P. Lawler, FPC Proj. No. 2338 (Jan. 16, 1974).

[25] 354 F.2d 608 (2d Cir. 1965), cert. denied, 384 U.S. 941 (1966).

[26] 16 U.S.C. §803(a).

[27] HRFI at 4.

[28] Id. at 4-5.

[29] Id. at 45.

[30] Scenic Hudson Preservation Conference v. FPC, 453 F.2d 463 (2d Cir. 1971), cert. denied, 407 U.S. 926 (1972).

[31] IP2 FES.

[32] In re Consolidated Edison Company of New York, Inc. (Indian Point 2), RAI-74-4 323.

[32] Hudson River Fishermen's Association v. Orange & Rockland Utilities, 72 Civ. 5460 (S.D.N.Y. 1972); Hudson River Fishermen's Association v. Central Hudson Gas & Electric Co., 72 Civ. 5459 (S.D.N.Y. 1972).

[33] Id.

[34] Id.

[35] Hudson River Fishermen's Association v. FPC, 498 F.2d 827 (2d Cir. 1974).

[36] 449 F.2d 1109 (D.C. Cir. 1971).

[37] See Urban Systems Research and Engineering, Inc., "Interceptor Sewers and Suburban Sprawl: The Impact of Construction Grants on Residential Land Use" (prepared for Council on Environmental Quality, 1974).

[38] E.g., Greene County Planning Board v. FPC, 455 F.2d 412 (2d Cir. 1972); Conservation Society of Southern Vermont v. Secretary, -F.2d-, 7 ERC 1236 (2d Cir. 1974).

[39] E.g., Letter of James W. Barnett, District Engineer to Central Hudson Gas & Electric Corp., 20 Dec. 1971, para. (W).

[40] Under Congress's new division of the AEC, national labs and the regulatory staff will be separated, the labs going into the Energy Research and Development Administration and the Regulatory Staff into the Nuclear Regulatory Commission.

[41] Letter of Herbert E. Doig to Kenneth F. Plumb, August 16, 1974 (Ex. 83A in 1974 hearings on FPC Proj. No. 2338).

[42] The Hudson River Fish and Wildlife Management Cooperative, Nov. 1973.

[43] 2 IP2 FES 45; Letter of Richard E. Griffith to Mark Abelson, April 28, 1971.

[44] Id.

[45] 2 IP2 FES 45.

[46] 2 IP2 FES 11.

[47] "Improved Federal Efforts Needed to Equally Consider Wildlife Conservation With Other Features of Water Resource Developments," GAO Report B-118370; Hearings Before the Subcommittee on Fish and Wildlife Conservation and the Environment of the Committee on Merchant Marine and Fisheries (93rd Cong., 2d Sess.) on GAO Report B-118370 and H.R. 42, H.R. 2283, H.R. 2288, H. R. 2291, H.R. 2292, H.R. 10651, and H.R. 14527 (Serial No. 93-33) ("Coordination Act Hearings") at 591, 600-605.

[48] Id. at 121-601.

[49] Two other federally established programs which might give backup support have also failed to provide technical assistance or a clear policy guidance. Congress gave its consent in 1940 to an interstate compact of the Atlantic coastal states for the joint regulation of the coastal fishery which clearly would encompass the estuarine dependent fishery (16 U.S.C. §367a), but the Atlantic States Marine Fisheries Commission established under the compact has not provided the technical analysis which would relate the production of estuaries to the coastal stock and thus the Commission has been unable to provide aid in determining the effect on the coastal fishery of development in the estuaries. Nor has the Department of the Interior used its statutory authority for Atlantic coast fishery studies to meet this need in relation to the Hudson. 16 U.S.C. §760a.

[49A] McHugh, "Marine Fisheries of New York State," 70 Fishery Bulletin 585 (1972); Ginter, "Marine Fisheries Conservation in New York State: Policy and Practice of Marine Fisheries Management," NYS Sea Grant Program, 1974 (NYSSGP-SS-74-012).

[50] 6 N.Y.C.R.R. Part 36; N.Y. Environmental Conservation Law §11-1511.

[51] Personal communication, James L. Biggane, formerly Commissioner, N.Y. Department of Environmental Conservation.

[52] In recent years, the New York Attorney General's office has moved to fill the vacuum and develop a state fishery policy through presentations before agencies and courts. Before the AEC, the attorney general took an active role generally supporting the position of the Oak Ridge staff, though no witnesses were presented. In the latest round of hearings before the FPC, the attorney general has been active and apparently plans to present witnesses as well as cross-examine those of other parties. The office also commented on the impact statement circulated by the Corps on the Bowline plant. In addition, the attorney general has brought a public nuisance suit against Consolidated Edison for fish destruction at the Indian Point plant. See Hudson River Fishermen's Association v. Consolidated Edison, N.Y. Law. Jour., June 6, 1971 at 2. This route for pursuing a fishery policy faces two important restraints. First, there are limited technical resources directly available to the attorney general, and it is unlikely that his office can develop the staff of fishery biologists, hydrologists, and computer experts needed for continuing analysis of the river. Second, the mandate of the attorney general does not extend to operating a management program for the estuarine fishery, so that a fully articulated program is unlikely to emerge from this effort.

[53] Remarks of J. L. McHugh at EPA Conference on Estuary Pollution Control, Feb. 11-13, 1975.

[54] Larkin, "A Confidential Memorandum on Fisheries Science," World Fisheries Policy: A Multidisciplinary View (Rothschild ed. 1972) 180.

[55] Consolidated Edison Company of New York, Inc., "Summary of Hudson River Research Programs, Approximate Cost of Ecological Studies" (Nov. 19, 1974).

[57] 120 Cong. Rec. S18724 (Oct. 10, 1974).

[58] Coordination Act Hearings at 591.

[59] Note 35, supra.

[60] 120 Cong. Rec. S18725 (Oct. 10, 1974).

[61] 42 U.S.C. §1857h-2; 33 U.S.C. §1335.

[62] 120 Cong. Rec. S18724 et seq.

ESTUARINE MANAGEMENT— THE INTERGOVERNMENTAL DIMENSION

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ABSTRACT

This paper provides a synoptic overview of the principal existing and pending federal laws and policies affecting the management of the nation's estuaries and estuarine zones. Specific attention is given to the influence these laws and policies have on the active management of such resources at the state, regional, and local levels. Using this analysis, the adequacy of extant federal policies to achieve established national goals and objectives on the preservation and conservation of estuarine resources is assessed. Finally, from this analysis current issues are identified, and proposed recommendations are made for federal policies to more adequately provide an institutional and management framework to protect these vital resources.

THE CURRENT SITUATION

The national government's concern and interest in protecting estuarine resources is relatively new. But the recognition that estuarine zones are productive and indispensable natural resources evolved only after many estuarine areas were lost to development and others imperiled.

During the decade of the 1960's dramatic growth and development experienced in the coastal states resulted in significant reduction of wetlands and the deterioration of some of our most valuable estuarine resources. The threat to these productive natural resources provoked legislative action in many coastal states and in Congress.

The first successful attempt to exercise a state's police power to protect estuarine resource systems came in Massachusetts with the enactment of that state's wetland legislation in 1963.[1] This statute requires a state permit as a condition to any significant alteration of coastal wetlands. It recognizes that these wetland areas are a natural resource held in trust for the people of the state, and usually a permit will not be issued if the proposed alteration would significantly damage estuarine and marine fisheries. The legitimacy of state regulation in these privately held areas was upheld by the Massachusetts courts.[2] The success of the Massachusetts law fostered enactment of similar statutes in many other coastal states. These state wetland laws were followed in a few states with a more comprehensive approach to coastal and estuarine management. Delaware,[3] Maine,[4] and California[5] are among the states that passed coastal zone management or conservation law.

Concurrent with many of these incipient state actions there was a national focus on oceanography. The Stratton Commission between 1967 and 1968 through its publication of "Our Nation And The Sea" [6] developed a greater federal and state awareness of the problems and opportunities in managing our coastal and ocean resources. The Stratton Report engendered a significant congressional interest in the vulnerability of the nation's coastal zone. The manifest congressional concern in estuarine resources was largely caused by this study, and culminated in the enactment of the so-called Estuary Protection Act of 1968 (P.L. 90-454). The Act provided for a study of the nation's estuaries, especially to determine if a "national system of estuaries" should be established. It also called for as national policy the protection, conservation, and restoration of the nation's estuaries, but in a manner that would maintain a balance between national needs for protection and conservation and the development of these estuaries to further growth and development. Moreover, the Act also asserts that the states have the basic responsibility for protecting the nation's estuarine resources.

In accordance with the mandate of the Act, the Department of the Interior issued a report in 1970 entitled "The National Estuary Study." This study, accomplished largely through outside consultants' contracts, examined the scientific, economic, governmental, and legal issues on the protection and management of estuarine resources. No specific legislative proposal emanated from the study, however.

Even without additional congressional policy on the protection of estuarine resources, other legislative and administrative actions began to influence the decisions involving development within these zones. The late 1960's brought an evolving environmental

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ethic within the federal establishment. The administration of the permit programs under the River and Harbors Act of 1899 (33 U.S.C. 403) by the Department of Army is a case study on this point.

Section 10 of this old statute prohibits the unauthorized obstruction or alteration of any navigable water of the United States. The Corps of Engineers had traditionally issued permits under the Act unless the proposal would interfere with navigation. However, the need to administer this legislation in accordance with contemporary environmental values caused a departure from this myopic approach. The vindication of this new federal environmental concern came in 1970 in the case of Zabel v. Tabb.[7] This litigation was brought after the District Engineer denied a Section 10 permit to fill 11 acres of tidelands in Boca Ciega Bay, Fla., on the grounds that the fill would be harmful to fish and wildlife. The 5th U.S. Circuit Court of Appeals held that the Corps of Engineers had properly taken conservation and environmental factors into account as well as navigational considerations. This holding was based on the Fish and Wildlife Coordination Act of 1959 (FWCA) and the National Environmental Policy Act of 1969 (NEPA). These statutes require consideration by federal agencies of environmental considerations other than missions assigned to them by their respective laws. The Supreme Court declined to review the case thereby letting the court of appeals' decision stand.

However, the general environmental impact analysis approach required under NEPA and FWCA were not considered adequate substitutes for substantive environmental policy. Congress recognized that impact assessments would not be adequate in areas requiring active resource planning and management.

Other Federal Legislation Relevant to Estuarine Management

The Senate and House Interior Committees did not follow up the "National Estuary Study" with proposed new legislation on protecting estuarine areas. But this was probably not associated with the merits of the study. Rather, the more likely reason for the absence of new estuarine legislation was the nature of the complex and overlapping committee structures in Congress. Several congressional committees exercise jurisdiction over legislation dealing with coastal and marine affairs. Quite independent of the activities in the Interior committees, these other committees were developing other legislative thrusts which happened to also directly affect the nation's estuarine zones.

Two such efforts culminated in 1972. The Senate and House Public Works Committees developed a major new water quality program in the Federal Water Pollution Central Amendment of 1972 (P.L. 92-500). This legislation protects estuarine resources in several ways. It requires the states to establish, under federal criteria, ambient water quality standards and effluent limitations. Compliance with these standards is obtained through a permit program encompassing all discharges into navigable waters. Areas having substantial water quality problems are required to develop continuous water quality management planning and programming processes under Section 208 of the Act. Such management planning must consider land use, curtailment of non-point sources, and, where appropriate, methods to control saltwater intrusion caused by curtailment of freshwater flow. Probably, the most important aspect of the statute on estuarine resources is the law's water quality goals for 1983. By that date, the nation's waters should provide for the protection and propagation of fish, shellfish and wildlife, and recreation in and on the water. Consequently, the Act establishes one absolute parameter for protecting and managing the estuarine zones.

On the other hand, the Coastal Zone Management Act of 1972 has a comprehensive rather than single purpose environmental orientation. It originated in the Senate Commerce and House Merchant Marine and Fisheries Committees. This law authorized the Secretary of Commerce to make grants to coastal states in planning for and administering sound management programs for the coastal zone. Its basic approach is that decisionmaking on the use of the coastal zone, which by definition encompasses the estuarine zone, is basically a state prerogative subject to the overriding national interest in such areas as water quality standards, navigation, deepwater ports, and the production of energy. To achieve this objective of state primacy, the legislation encouraged the establishment of a management process including an intergovernmental system to achieve wise use of land and water resources of the coastal zone. One of the principal inducements for the state to develop an unified management program for the areas is that, when approved, the state management process will subject the federal government's actions to stringent consistency checks against adopted state policies. Under Section 307, application for a federal grant, license or permit to conduct activities affecting land water uses in the state's coastal zone must be consistent with the state's approved coastal management program. Normally, direct federal government activities must also be consistent with the state program.

The Act also recognizes the particular value of preserving estuarine resources. Under Section 312, the Secretary is authorized to make grants up to 50 percent of the cost of acquiring and operating estuarine sanctuaries for the purpose of creating natural field laboratories to study the natural and human processes within estuaries.

In 1972, Congress also enacted the Marine Protection, Research and Sanctuaries Act of 1972 (P.L. 92-532). The Act mainly affects ocean resources. But it also will assist in the protection of the waters within estuarine zones. This results from two programs provided for in the legislation. Section 103 requires the Secretary of the Army to issue permits for the transportation of dredged material for the purpose of dumping it in ocean waters. No such permit may be issued, however, if the Administrator of EPA finds that the dumping of such material will result in an unacceptable adverse impact on shellfish beds, fisheries, wildlife, or recreational areas. Moreover, the protection of estuarine areas will be assisted also under the authority in Section 302 of the Act. This provision vests the power in the Secretary of Commerce, after consultation with other federal agencies and with approval of the President, to designate as marine sanctuaries those areas of ocean or coastal waters which he determines necessary to preserve or restore such areas for their conservation, recreational, ecological, or aesthetic values. Once designated, the Secretary must issue regulations to control any activities within such areas, and federal activities can only be undertaken in these sanctuaries if the Secretary certifies that they are consistent with the management of the area as a marine sanctuary.

Finally, a summary of the existing environmental policies affecting the protection of estuaries, or any other important natural resource, would not be complete without including the National Environmental Policy Act of 1969 (P.L. 91-190). This far-reaching statute declares it the national policy to encourage a productive and enjoyable harmony between man and his environment. To assure that this policy is incorporated into all the programs and actions of the federal government, Section 102 of the Act directs that to the greatest extent possible the policies, regulations, and public laws of the United States shall be interpreted and administered to reflect the purposes of the Act. This section also mandates all federal agencies to prepare detailed environmental impact statements on major federal actions significantly affecting the quality of the human environment. Such statements are to insure that environmental amentities and values will be given appropriate consideration in federal decision-making processes.

While NEPA does not establish absolute environmental standards, it provides the integrative force to focus all appropriate environmental policies and values on major federal programs and regulatory systems.

Proposed Federal Legislation

The national energy crisis is becoming an important new factor in protecting estuarine resources. To become more self-sufficient, additional energy sources are being sought. One of the prime areas for new oil exploration is in the Outer Continental Shelf. But exploration for new energy sources is not the only approach contemplated to meet the problem. For example, coastal and estuarine areas are attractive locations for new power plants, especially nuclear facilities.

In response to those needs, the Department of Interior has indicated that areas in the Baltimore Canyon area of the Continental Shelf adjacent to the states of New Jersey, Maryland, Delaware, and Virginia will be opened to oil exploration in 1975. Existing production areas will be subject to more intense exploration activities. As a result, the Administration has requested and Congress has appropriated supplemental funds for FY 1975 to accelerate the coastal state planning efforts to prepare for the impact of these energy-inspired activities in the offshore areas. These monies will be available to the coastal states under the Coastal Zone Management Act of 1972.

Congress has also evinced interest and concern over the potential environmental consequences of new energy development activities. For example, the Senate has established the National Ocean Policy Study Group in the Commerce Committee.[8] In April 1974, the Committee received testimony on the potential impact of Outer Continental Shelf oil and gas development along the Atlantic, Pacific, and Gulf of Alaska. Much of the testimony recognized that the nearshore areas of the coastal zone would absorb a major part of the environmental impact. One federal official cited the impact of offshore drilling in the Gulf of Mexico as evidencing that these activities would cause loss of wetlands and affect circulation conditions of nearshore areas.[9]

These and other congressional hearings have generated a plethora of bills dealing with the environmental consequences of development in the continental shelf area.[10] One of these measures was enacted in the last days of the 93rd Congress—Deepwater Port Act of 1974 (P.L. 93-627). In the main, the Act authorized the Secretary of Transportation upon application to issue, transfer, and renew 20-

year licenses for the ownership, construction, and operation of deepwater ports in waters beyond the territorial limits of the United States. This legislation is simply a recognition by the executive branch and Congress that new domestic energy sources are not the immediate answer to our problem. Rather, oil imports will continue and the United States must have adequate facilities to accommodate the ever-increasing fleet of supertankers. Again, as in the case of new offshore exploration, any such legislation will inevitably have significant impact on estuarine areas, albeit of a more localized nature.

Impact of Federal Law and Policy on Estuarine Management Act State and Substate Level

Most of the federal legislation discussed above affecting estuarine areas have a single thrust; they encourage states to develop balanced management processes for such areas. The Estuary Protection Act and the Coastal Zone Management Act represent this policy. In the former case the legislation has had little impact in generating state management policies for wetland and estuarine areas. Its most important contribution has been to perpetuate continuing congressional interest in estuarine problems and, to some extent, cause federal agencies to consider state policies relative to the management of these resources. A good example of the latter is the Corps of Engineers' use of the Act as the basis for considering state policy and the administration of its permit programs concerning activities in navigable ocean waters.[11]

On the other hand, the Coastal Zone Management Act has had widespread impact on estuarine management. It appears that all coastal and Great Lake states will participate in the program. This will have direct implications on estuarine management. The Act and its implementing regulations require each participating state to evolve over a period not to exceed three years a unified coastal zone management program, together with a coordinated administrative system for its implementation. Thus the Act supports a substantial increase in state law and authority in the estuarine zone.[12] The program must identify important coastal resource areas such as estuarine zones. It must insure that such resources are encompassed in the state's defined coastal zone. Further, discreet policies must be adopted for their protection, conservation, and development. The defined coastal zone also must include upland areas necessary to control uses of land which have a direct and significant impact on coastal waters.

To insure adequate implementation of the management program, and to resolve conflicts of competing uses, each participating state must have a technique to control land and water uses in the coastal zone. Although several options are available, most states will probably establish standards and criteria for implementation by local governments. Many states also intend to use regional planning agencies to assist in implementing the program.

As pointed out above, the program is not mandatory. States are encouraged to participate and receive two-thirds of the cost of developing a coastal management program. Such development grants can be made annually for three years. After that period a state may only receive annual grants toward the cost of administering its program if the Secretary of Commerce approves the program. A principal inducement for securing program approval is that subsequently the federal government must generally conduct its programs and activities in accordance with the approved state management program.

Already the coastal management program is having significant impact on state, regional, and local governments. If most coastal states remain in the program, state and local government will be making explicit planning and policy-based decisions on the future use of estuarine resources. Most importantly, however, such decisions will be made within the framework of a coastal management process which will weigh environmental as well as economic and social values. It must be reiterated that the importance given estuarine resources in this process is essentially a state value judgment. Unless there is a preemptive national policy, as in the case of the Federal Water Pollution legislation, the state's perception of estuarine management must prevail.

The Federal Water Pollution Control Act of 1972 had the most immediate impact on the management of estuarine resources at the state and local levels. Prior to this Act, federal policies dealing with water quality impacts on estuarine waters and coastal wetlands were diffuse and ambiguous. But the Act provided definitive standards and goals which encompassed all of the nation's navigable waters. Currently, EPA and the Corps of Engineers' regulations involving the various permit programs under the Water Act and the Refuse Act extend federal water quality standards into wetland areas. Therefore, federal or state permits for any alteration in wetland areas must now be evaluated in the terms of their effect on water quality. The application of the water quality standards in these areas by EPA has been upheld by the United States District Court in Florida.[13]

The NEPA has also fostered the consideration of related federal environmental policies in these per-

mit programs. As indicated above, for example, the Corps of Engineers' regulations on permits for activities in navigable waters or ocean waters under the Refuse Act and the Marine Protection Act require consideration of the proposed activity on wetlands and the estuarine zone.[14] In the former case, the federal policy on wetlands has been administratively derived, and in the latter the implications on estuarine management reflect the general policies in the Estuary Protection Act. But there is little doubt that the integration of these related environmental policies was brought about largely through the mandate in NEPA.

ESTUARINE MANAGEMENT— THE FEDERAL POLICY ISSUES

No single federal policy focuses on developing new initiatives to protect the nation's estuarine areas. This lack of central responsibility does not indicate absence of congressional or federal executive concern, however. Indeed, there is no paucity of federal law and administrative regulations pertaining to these resources. On this point some would suggest the federal presence in these areas is already too large. Congress apparently does not share this view. If they did, the continuing requirement to study these areas such as that contained in Section 104(n) of the Federal Water Pollution Control Act would not be necessary. Rather, it can be argued that the central national concern is the need to evaluate the adequacy of existing estuarine policy, and to do so as a part of a critical examination to determine the appropriate federal role. The ancillary issues emanating from this proposition are discussed below.

For the purpose of analysis, current federal policy affecting estuarine resources can be fitted into three basic categories.

The first may be described in terms of actual federal acquisition of estuarine resources. Under congressional authorization, the Department of Interior has acquired areas of particular national interest. Typically, they are wilderness areas or areas suitable for recreational use. Many estuarine areas are contained in this national parks system. But they represent a small segment of our total estuarine resources.

The second category of this federal policy involves regulatory and coordinative efforts. With the exception of the Estuary Protection Act and administratively established policies on wetlands, these programs only have incidental application to estuarine zones. Their main purpose is to protect some other natural resource value, e.g., Fish and Wildlife Coordination Act.

The last category involves encouraging states to develop comprehensive resource management programs. Of course, the Coastal Zone Management Act is the most relevant to estuarine management in this regard.

As indicated above, these disparate policies reflect the structure of Congress and the federal executive branch. There is no single locus in the system which has the exclusive responsibility for natural resource management. Consequently, the various executive agencies sharing responsibility coordinate their efforts through informal or ad hoc interagency mechanisms. This can be a positive exercise, but too often agency mission and interest make it difficult for such peer groups to arrive at balanced or comprehensive decisions. As a result, there is no central or uniform federal executive policy on the protection of the nation's estuarine resources. Moreover, the National Environmental Policy Act does not adequately fill this gap. It does cause federal grant and regulatory decisionmakers to consider the totality of federal environmental policy when arriving at decisions affecting estuarine resources. In this process only congressionally-mandated environmental standards, e.g., water and air quality standards, are absolute, however. All other environmental factors are subjectively weighed by the federal agency entrusted with the final decisionmaking authority. In such a coordinative management process policies of state and local government on estuarine management are often critical. Both the Estuary Protection and the Coastal Zone Management Act require federal agencies in making decisions affecting estuarine resources to comply with state policies if they are not in conflict with the national interest.

Based on the above survey of current federal policies on protecting estuarine resources, the following major issues have been identified:

- *Will the federal incentives to encourage states to develop coastal zone management programs result in adequate state and local government programs for the protection or prudent use of estuarine resources?*

The initial response by the state is salutary. The real test will come, however, when they propose coastal management programs for approval by the Secretary of Commerce. At that time a determination must be made from a national perspective on whether the several states have identified estuarine areas as areas of particular concern, with appropriate managerial constraints placed on their use, including related land uses.

- *Are there adequate federal policies to insure that development encroaching on estuarine areas will be adequately managed by state and local governments to protect the estuarine resources?*

The Coastal Zone Management Act goes a long way toward achieving this result. It has certain geographical constraints, however. A state's coastal zone may only include inland areas necessary to control uses which have a direct and significant impact on coastal waters. This boundary may be adequate in most cases to protect estuarine areas. However, in densely populated metropolitan regions the pressures of development in the areas immediately adjacent to the coastal zone may exert pressures which ultimately result in development in the zone itself. This void could have been filled if national land use legislation had been enacted. In its absence, other approaches must be sought. This will necessitate close coordination among federal agencies having complementary programs affecting state and local government land use policies. The comprehensive planning grant assistance program[15] administered by the Department of Housing and Urban Development and EPA's area-wide water quality management planning program[16] will influence land use decisions in the areas adjacent to the coastal zone.

• *Is the administratively established policy on wetlands adequate to protect estuarine resources?*

Presently, federal policies on wetlands have been derived without an explicit congressional mandate. And they have become important considerations in making federal regulatory and development decisions within these areas, especially in those states which do not presently have adequate wetland protection policies. However, as administrative policy they do not have the same standing as legislation. This makes the application of these policies particularly vulnerable in cases where the only potential constraint on a proposed activity is the federal wetland policy itself.

• *Are current federal policies for the protection of estuarine areas adequate to ameliorate impending development pressures caused by the impact of oil and gas exploration in the Outer Continental shelf to meet the energy crisis?*

This is probably the most serious national challenge to the preservation of our estuarine areas. Since the federal government has exclusive control in the development of OCS resources, the states are vulnerable to the impact of such activities. Advanced and joint federal-state planning for the onshore impacts is vital. The proposed federal planning grant funds for this purpose will assist in minimizing potential adverse effects on coastal and estuarine resources. If adverse environmental impact from such exploration and other energy development activities is to be minimized, however, additional federal impact assistance to coastal states will be required.

RECOMMENDATIONS

In responding to the aforementioned issues the following recommendations are offered:

• A federal interdepartmental estuarine task force should be established, probably as an adjunct to the federal coordination responsibilities of the Department of Commerce in the administration of the Coastal Zone Management Act. This group would be charged with: 1) identifying existing federal laws and policies affecting estuarine management and synthesizing them into unified federal policy for uniform application throughout the federal establishment; 2) developing objective evaluation criteria to determine the adequacy of state programs and regulatory policies on the protection and use of estuarine resources, including related land uses; and 3) examining the current administratively established federal wetland policies, and preparing and recommending to Congress a legislative program for wetland protection to be applicable to all federal grant-in-aids and regulatory programs, as well as direct federal management and development activities.

• Develop legislation to provide federal impact aid funds to coastal states. These federal funds should be available to minimize adverse environmental effects and control associated social impacts caused by the development of energy resources in the coastal zone and Outer Continental Shelf. Such grants should be conditioned on advance planning and programming for these impacts under the Coastal Zone Management Act. The acquisition of lands, construction of public facilities, and the provision of public services within the impact coastal areas should be eligible activities under this program.

FOOTNOTES

[1] Chapter 130-Section 27A as amended, Massachusetts General Laws.

[2] Commissioner of Natural Resources v. S. Volpe & Co., 349 Mass. 104, 206 N.E. 2d 666 (1965).

[3] Delaware Coastal Zone Act of 1971, 7 Del. Code Ch. 70, 7001, et seq.

[4] Maine Site Location Act, 38 M.R.S.A. 481–488 (1970).

[5] California Coastal Zone Conservation Act of 1972, Public Resources Code, 27000 et seq.

[6] Julius A. Stratton, Chairman, Commission on Marine Science, Engineering and Resources established by P.L. 89-454. The Commission published as its final report Our Nation and the Sea, and three panel reports.

[7] Zabel v. Tabb, 430 F.2d 199 (5th Cir. 1970).

[8] Senate Resolution 222 established in the Senate Commerce Committee the National Ocean Policy Study Group.

[9] Robert M. White, Administrator, National Oceanic and Atmospheric Administration, Department of Commerce, in a prepared statement before the National Ocean Policy Study Group, Senate Commerce Committee, April 23, 1974.

[10] e.g., S. 3221, Energy Supply Act of 1974; S. 2858 Outer Continental Shelf Safety Act of 1974; S. 2672, Marine Resources and Conservation Act of 1974; S. 5, Deepwater Port Act of 1974, all introduced in the 93rd Congress.

[11] Disposal of Dredged Material in Navigable and Ocean Waters, 33 C.F.R. 209, 145.

[12] Specific indications of the growth in state law and authority can be found in the Office of Coastal Zone Management's State Coastal Zone Management Activities—1974, and Bradley and Armstrong, A Description and Analysis of Coastal Zone and Shoreland Management Programs in the United States, March 1972.

[13] United States v. Holland, 4 ELR 20710 (M.D. Fla., Mar. 27, 1974).

[14] Supra, Note II.

[15] Section 701, Housing Act of 1954, as amended.

[16] Section 208, Federal Water Pollution Control Act Amendment of 1972 (P.L. 92-500).

BASIC FACTORS OF POPULATION DISTRIBUTION AFFECTING DEMAND FOR WATER RESOURCES

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ABSTRACT

The number of people is not the critical factor in water pollution, but the way the population is distributed and the life patterns that are followed. This report describes the changing distribution of the population of the estuarine counties of the eastern seaboard including the development of new urban structures such as the megalopolis and the creation of new lifestyles brought about by increased leisure time, retirement, second homes, commuting, female participation in the labor force, and changing residential arrangements.

INTRODUCTION

Evidence is accumulating that water will be the focus of a great world environmental crisis of the future. The pressures of very rapid population growth, industrialization, and improvements in the levels of living will be followed by a steadily increasing consumption of water. A result will be pressures for a more complete utilization of existing water resources everywhere.

Widely publicized food shortages have resulted from a serious drought in many countries since 1972. Some climatic experts insist that the world may be entering into a new cycle of drought that may last for a number of years. The reaction to predicted lack of precipitation will be development of wells and dams that permit irrigation of large tracts of land; such a step could have serious ramifications for both the quantity and even more importantly, the quality of water.

In the United States these pressures will most likely result in an acceleration in the use of water in the estuaries of the eastern seaboard; a subsequent deterioration of these water resources is quite likely unless preventive action is taken in the immediate future. The possible deterioration of water resources is related to the changing life patterns of the human population, patterns that can bring immense changes in the environment.

Already the almost solid configuration of cities and industry along most of the northern portion of the eastern seaboard has resulted in widespread pollution of the estuaries. The limited concentrations of population and industrial developments have spared much of the southern coastal areas from these problems.

Acknowledging that problems of pollution are manmade, it is appropriate to analyze the changing distribution of the population along the eastern seaboard and to ascertain some of the trends in American life that affect the water resources.

The basic theme of this report is that the mere number of people is not the critical factor in the water pollution of a given area, but rather, the way in which the human population is distributed. Above all, the life patterns of mankind determine the impact he has upon his environment. Thus, there are two major sections to this analysis: First, a description of the changes that are taking place in the distribution of the population, especially along the east coast; and second, some of the changes in the life patterns of the American population, especially demographic trends, which have relevance to the relationship of the human population to the natural environment.

The logic of this approach to understanding water pollution is demonstrated by the following definition agreed to at a Geneva conference in 1961, "a water is considered polluted when its composition or state is directly or indirectly modified by human activity to the extent that it is less suited for purposes it could have served in its natural state" (Furon, 1967:105).

Although technically the definition may be inadequate, one has but to glance at a few of the myriad products of human behavior which do pollute the water of the world—pesticides, fertilizers, industrial effluents, raw sewage, synthetic detergents, and

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household refuse—to realize that the problem is widespread and serious (Furon, 1967:106–108).

GENERAL TRENDS IN POPULATION DISTRIBUTION

At the time of the first census of the United States in 1790, the population of the country was 3,929,214, largely restricted to a narrow band along the east coast. The rate of growth per decade ran over 30 percent from 1790 until 1880 with the exception of the 10-year period from 1860 to 1870. In this era of the Civil War the growth rate remained high, amounting to 22.6 percent. Although after 1880 the decennial rate of growth started declining, it was still 25.5 percent between 1880 and 1890.

The 100 years between 1790 and 1890 witnessed the westward movement of the population until settlement was virtually complete from the east to the west coast. The population of the nation increased manyfold after 1790 and stood at 62,979,766 when the census was taken in 1890.

This westward movement, the Civil War, and changing agriculture brought the abandonment of many farms and plantations along the eastern seaboard. Rice production completely disappeared from Georgia and South Carolina. The chain of islands along the coastal areas of the south at one time had large cotton plantations when water was the principal medium of transportation. The fields were permitted to become fallow and forests were soon soon established as the population shifted to the mainland.

At the beginning of the 19th century, the United States was basically a nation of agriculturists. Only 5 percent of the country's population resided in cities when the census was taken in 1790. Around a decade later the growth of cities became an all pervasive phenomenon, not only in the United States, but the rest of the world as well. In 1850, 15.3 percent of the population of the nation lived in cities, but by 1900, the figure had increased to 39.6 percent. Some theorists have associated the growth of the cities with the development of the railroad as a major means of transportation. By 1920, 51.2 percent of the inhabitants of the United States lived in cities. These cities were largely constructed about the intersection of railroads or where they terminated at ocean ports.

With the advent of the automobile, the stage was set for a modification in the urbanization process. Increasingly, people could reside farther and farther into the suburbs and still work in the central business district. The growth of cities continued until in 1940, 56.5 percent of the nation's population resided in urban areas, that is, population centers with over 2,500 inhabitants.

Accelerating since the 1940's was a second urban revolution—the rapid decentralization of cities. The metropolitan region became the focus of human existence. Practically all of the hundreds of modern shopping centers that dot the American landscape on the periphery of the major cities have been constructed since World War II. A concomitant of this decentralization has been the loss of function by the central business district; the decay of these inner cities was widely publicized during the 1960's. Nevertheless, the urban population, including the suburbs adjacent to the major urban centers, continued to grow. In 1970, nearly three out of four American citizens (73.5 percent) were classified as urban.

A third revolution in the growth of cities, an urban sprawl, seems underway (Gottman and Harper, 1967). The largest urban areas of the United States are now starting to lose population. Between 1960 and 1970, 15 of the 21 cities in the United States with populations above 500,000 in 1960 actually lost population. More recent estimates indicate that this trend is accelerating and that a very large percentage of the major cities of the nation will lose population during the decade of the seventies, at the same time the urbanized portion of metropolitan areas tends to spread over the countryside.

At the same time, it needs to be emphasized that the population of the nation continues to grow rapidly, reaching 213,000,000 during the fall of 1975. Ours remains essentially an urban population with people living on the fringes of the larger cities in an ever-widening radius. This fringe development has been a major phenomenon of recent years and is likely to continue. On the other hand, the probability that the central cities will experience rebirth and renewed population growth is remote.

The cities of the United States have grown largely through young people abandoning the farms for life in the cities. This rural to urban migration was a major factor in the redistribution of the population over the last 150 years. This migration was enhanced by the immigration of thousands upon thousands of foreign born during the late 19th and early 20th centuries. There were several years in which over a million immigrants came to the United States, settling generally in the central core of the larger cities. Currently, the effect of immigration on the growth of central cities has declined because immigration proceeds at a slower rate than previously, and because the modern immigrant tends to join relatives who may be scattered throughout the nation, rather than in the urban ghettos.

Even more important for the growth of cities is

that the rural-farm population base is so small. Only 5.2 percent of the nation's inhabitants lived on farms in 1970. The birth rates of the rural farm residents are declining to a level comparable to those of the rest of the nation's citizens. Cities simply cannot depend upon a continuation of the in-migration of a surplus rural population as a source of growth. Urban growth must come from a natural increase.

In spite of the fact that the population of the nation is increasing rapidly, it is obvious that all sections are not equally sharing this growth. Of the 3,124 counties and county equivalents in the United States, about one-half actually lost population between 1960 and 1970, a decade in which the total population increased by nearly 24,000,000. Less than one-third of these counties grew through immigration.

The greatly reduced birth rates of the seventies means that rapid growth for an area must be sustained by internal migration. The redistribution of the population draws an increasing portion of the population away from the vast midlands of the continent to the coastal areas (See Figure 1) (Ullman, 1954), although the coastal counties of the southern United States have not experienced rapid growth through internal migration in recent years.

"The only areas of the country in which more than half the total population increase was due to net immigration were Florida, the coastal portions of the Pacific Northwest, and California. Collectively, these three areas had a net inflow of more than 4 million persons in the 1960's, whereas the remainder of the country had a net migration loss of nearly 1 million" (U.S. Bureau of the Census, 1974:129).

These trends in the redistribution of the population are especially important for those concerned with changes along the seaboard of this nation. The population, for example, in the coastal counties of the eastern seaboard contained 16.7 percent of the total population of the nation in 1950. This percentage has slowly but steadily increased to 17.1 percent in 1960, 17.4 percent in 1970, and the latest population estimates as of July 1, 1973 show that 17.5 percent of the nation's population lives in these counties. (See Table 1). The total population of these coastal and estuarine counties has increased from 25,283,811 in 1950, to 36,921,600 in 1973. Another way to look at the tendency of the population to live in coastal areas is that this band of seaboard counties experienced a 21.8 percent increase between 1950 and 1960. At the same time the population of the nation as a whole was increasing 18.6 percent. During the next decade these coastal counties increased 15.6 percent compared with an increase of 13.5 percent in the total population of the United States. The latest estimates show that between 1970 and 1973 these estuarine counties increased 3.8 percent while the nation's population increased 3.0 percent.

Many people have become aware recently that the nation's birth rates have fallen to the lowest point in history. A real possibility exists that population increase in the nation may fall below the replacement level within the next very few years, especially if economic conditions worsen. At the present time the crude birth rate is about 14.8 per thousand and the death rate is 9.2 per thousand. As the average age of the population increases, it is inevitable that the death rate will rise. If the birth rate continues the decline that started in 1957 and rapidly accelerated about 1965, there will be a balance between births and deaths within, perhaps, the next 15 years.

A reduction in the rate of growth or even a period in which the population of the nation reaches stability does not mean that the number of residents in the coastal counties will reach an equilibrium. In fact, trends point to further rapid population growth in the estuarine areas almost independent of what occurs to the total population of the nation.

NEW URBAN STRUCTURES

The growth of cities covers a much wider range of developments than is often recognized. Most people in the United States have a stereotyped image of the city based on the concentric zone model in which the central business district is surrounded by low income housing and industrial activities. As one moves out from this center toward the suburbs the quality and spaciousness of the homes improves. Growth is thought of as occurring in concentric rings as the population continues to move out from the center in all directions.

Actually the city has taken many forms in human history. What we tend to think of as a city in the United States is basically a product of the 19th century when the urban structure was based upon aggregations of industry at a major railway center. By contrast, the cities of antiquity did not have the central business districts characteristic of this country. The nucleus of the city does not always have a commercial function. The center of the city may be either a religious shrine, a political center, or a university.

We may anticipate that the American city of the future will have a much different structure than is common at present. One indicator of this change

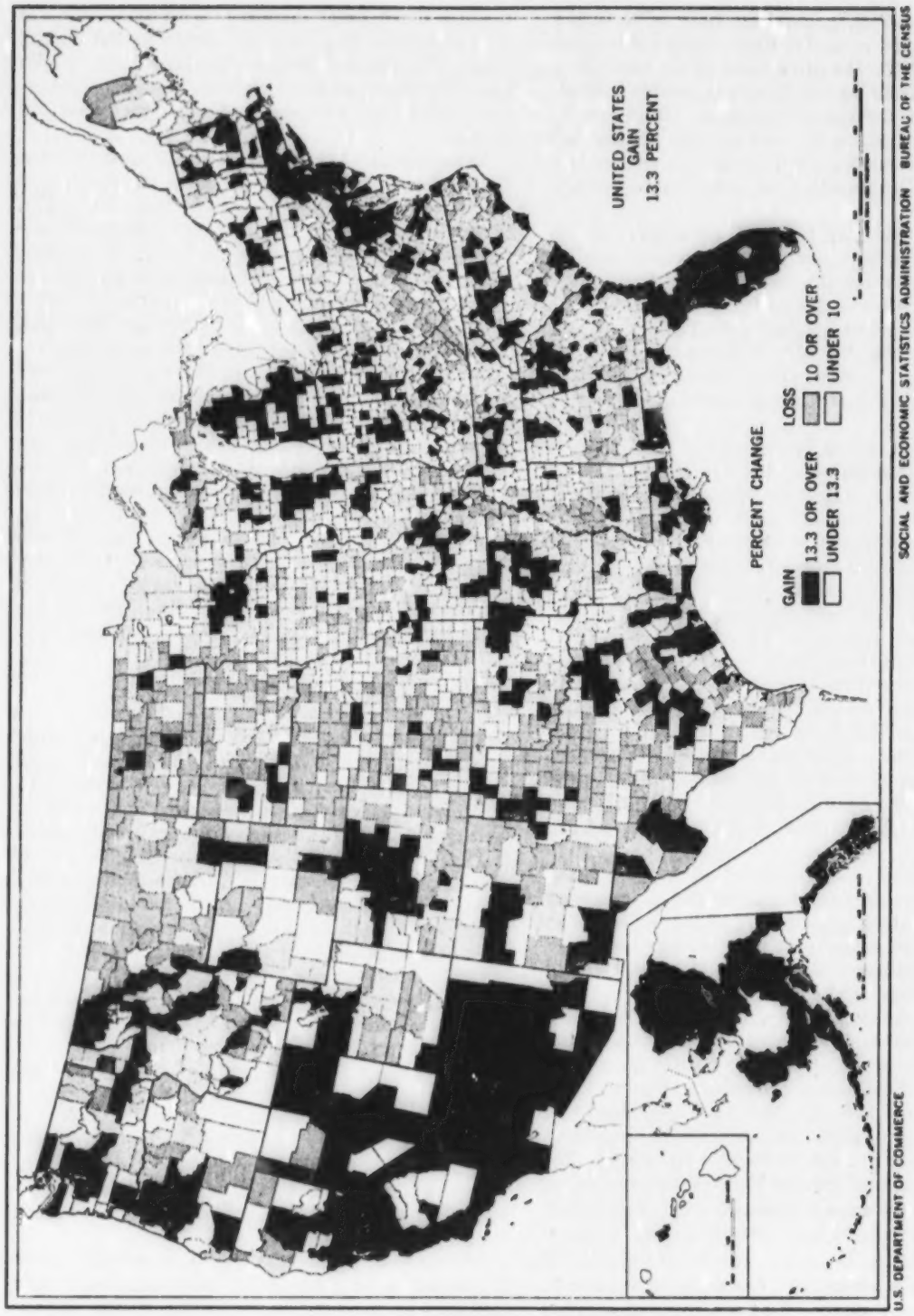

FIGURE 1.—Percent of change in total population by counties: 1960 to 1970.

Table 1.—Total population of estuarine counties of the Eastern Seaboard, 1950–1973.

	1950	1960	1970	1973
MAINE				
Cumberland	169,201	182,751	192,528	197,200
Hancock	32,105	32,293	34,590	37,000
Knox	28,121	28,575	29,013	31,100
Lincoln	18,004	18,497	20,537	21,600
Sagadahoc	20,911	22,793	23,452	24,900
Waldo	21,687	22,632	23,328	25,500
Washington	35,187	32,908	29,859	31,200
York	93,541	99,402	111,576	117,600
TOTAL	418,757	439,851	464,883	486,100
NEW HAMPSHIRE				
Rockingham	70,059	99,029	138,951	153,700
TOTAL	70,059	99,029	138,951	153,700
MASSACHUSETTS				
Barnstable	46,805	70,286	96,656	109,000
Bristol	381,569	398,488	444,301	461,300
Dukes	5,633	5,829	6,117	6,900
Essex	522,384	568,831	637,887	647,400
Nantucket	3,484	3,559	3,774	4,200
Norfolk	392,308	510,256	604,854	614,300
Plymouth	189,468	248,449	333,314	364,700
Suffolk	896,615	791,329	735,190	734,700
TOTAL	2,438,266	2,597,027	2,862,093	2,942,500
RHODE ISLAND				
Bristol	29,079	37,146	45,937	46,100
Kent	77,763	112,619	142,382	148,700
Newport	61,539	81,891	94,228	99,700
Providence	574,973	568,778	581,470	586,300
Washington	48,542	59,054	85,706	92,200
TOTAL	791,896	859,488	949,723	973,000
CONNECTICUT				
Fairfield	504,342	654,589	792,814	787,800
Middlesex	67,332	88,865	115,018	121,000
New Haven	545,784	660,315	744,948	756,800
New London	144,821	185,745	230,654	239,800
TOTAL	1,262,279	1,588,514	1,883,434	1,905,400
NEW YORK				
Albany	239,386	272,926	286,742	288,700
Bronx	1,451,277	1,424,815	1,471,701	1,449,200
Columbia	43,182	47,322	51,519	55,900
Dutchess	136,781	176,008	222,295	229,700
Greene	28,745	31,372	33,136	37,200
Kings	2,738,175	2,627,319	2,602,012	2,507,100
Nassau	672,765	1,300,171	1,428,080	1,412,400
New York	1,960,101	1,698,281	1,539,233	1,463,800
Orange	152,255	183,734	221,657	233,600
Putnam	20,307	31,722	56,696	63,500
Queens	1,550,849	1,809,578	1,987,174	1,984,600
Rensselaer	132,607	142,585	152,510	155,700
Richmond	191,555	221,991	295,443	312,000
Rockland	89,276	136,803	229,903	240,100
Suffolk	276,129	666,784	1,127,030	1,197,200
Ulster	92,621	118,804	141,241	151,600
Westchester	625,816	808,891	894,406	891,100
TOTAL	10,401,827	11,699,106	12,740,778	12,673,400

	1950	1960	1970	1973
NEW JERSEY				
Atlantic	132,399	160,880	175,043	185,100
Bergen	539,139	780,255	897,148	897,900
Burlington	135,910	224,499	323,132	323,500
Camden	300,743	392,035	456,291	474,200
Cape May	37,131	48,555	59,554	65,900
Cumberland	88,597	106,850	121,374	130,900
Essex	905,949	923,545	932,526	936,900
Gloucester	91,727	134,840	172,681	181,300
Hudson	647,437	610,734	607,839	617,700
Mercer	229,781	266,392	304,116	316,100
Middlesex	264,872	433,856	583,813	597,100
Monmouth	225,327	334,401	461,849	477,800
Ocean	56,622	108,241	208,470	250,000
Salem	49,508	58,711	60,346	62,300
Union	398,138	504,255	543,116	546,300
TOTAL	4,103,280	5,088,049	5,907,298	6,062,800
VIRGINIA				
Accomack	33,832	30,635	29,004	29,200
Arlington	135,449	163,401	174,284	163,800
Caroline	12,471	12,725	13,925	14,400
Charles City	4,676	5,492	6,158	6,600
Chesterfield	40,400	71,197	77,045	90,400
Dinwiddie	18,839	22,183	25,046	22,800
Essex	6,530	6,690	7,099	7,100
Fairfax	98,557	275,002	455,032	514,000
Franklin	24,560	25,925	28,163	29,600
Gloucester	10,343	11,919	14,059	115,600
Hanover	21,985	27,550	37,479	43,300
Henrico	57,340	117,339	154,364	165,300
Isle of Wight	14,906	17,164	18,285	18,700
James City	6,317	11,539	17,853	19,100
King and Queen	6,299	5,889	5,491	5,400
King George	6,710	7,243	8,039	8,500
King William	7,589	7,563	7,497	7,500
Lancaster	8,640	9,174	9,126	9,200
Loudoun	21,147	24,549	37,150	41,700
Mathews	7,148	7,121	7,168	7,800
Middlesex	6,715	6,319	6,295	6,500
Nansemond	25,238	31,368	35,166	
New Kent	3,995	4,504	5,300	6,300
Norfolk	99,937	51,612		
Northampton	17,300	16,966	14,442	15,300
Northumberland	10,012	10,185	9,239	9,100
Prince George	19,679	20,270	29,092	19,800
Princess Anne	42,277	76,124		
Prince William	22,612	50,164	111,102	129,100
Richmond	6,189	6,375	6,504	6,300
Southampton	26,522	27,195	18,582	18,200
Spotsylvania	11,920	13,819	16,424	19,200
Stafford	11,902	16,876	24,587	27,900
Surry	6,220	6,220	5,882	6,200
Westmoreland	10,148	11,042	12,142	12,900
York	11,750	21,583	33,203	36,800
Independent Cities:				
Alexandria	61,787	91,023	110,927	105,000
Chesapeake			89,580	93,900
Colonial Heights	6,077	9,587	15,097	16,900
Fairfax			22,009	21,600
Falls Church	7,535	10,192	10,772	10,300
Franklin			6,880	6,700
Fredericksburg	12,158	13,639	14,450	15,400
Hampton	5,966	89,258	120,779	127,300
Hopewell	10,219	17,895	23,471	23,800
Newport News	42,358	113,662	138,177	137,500
Norfolk			307,951	283,100

Table I.—Total population of estuarine counties of the Eastern Seaboard, 1950-1973.—(Continued)

	1950	1960	1970	1973
VIRGINIA—(Cont.)				
Petersburg	35,054	36,750	36,103	33,600
Portsmouth	80,039	114,773	110,963	109,100
Richmond	230,310	219,958	249,431	230,400
South Norfolk	10,434			
Suffolk	12,339	12,609	45,024	47,400
Virginia Beach		8,091	172,106	192,900
Williamsburg	6,735	6,832	9,069	10,200
TOTAL	1,387,165	1,975,139	2,942,965	3,008,700
MARYLAND				
Anne Arundel	117,382	206,634	298,042	321,700
Baltimore	270,273	492,428	620,409	637,500
Baltimore City	949,708	939,024	905,789	871,300
Calvert	12,100	15,826	20,682	23,700
Cecil	33,356	48,408	53,291	55,300
Charles	23,415	32,572	47,678	54,600
Dorchester	27,815	29,686	29,405	28,800
Harford	51,782	76,722	115,378	129,100
Kent	13,677	15,481	16,146	16,500
Prince Georges	194,182	357,395	661,087	695,000
Queen Annes	14,579	16,569	18,422	19,000
Saint Marys	29,111	38,915	47,388	49,000
Somerset	20,745	19,623	18,924	18,600
Talbot	19,428	21,578	23,682	24,800
Wicomico	39,641	49,050	54,236	56,900
Worcester	23,148	23,733	24,442	25,500
TOTAL	1,840,352	2,388,624	2,954,994	3,027,300
DELAWARE				
Kent	37,870	65,651	81,892	89,900
New Castle	218,879	307,446	385,856	408,000
Sussex	61,336	73,195	80,356	85,800
TOTAL	318,085	446,292	548,104	575,700
NORTH CAROLINA				
Beaufort	37,134	36,014	35,980	36,100
Bertie	26,439	24,350	20,528	20,300
Brunswick	19,238	20,278	24,223	29,800
Camden	5,223	5,598	5,453	55,600
Carteret	23,059	27,439	31,603	33,600
Chowan	12,540	11,729	10,764	10,600
Craven	48,823	58,773	62,554	67,000
Currituck	6,201	6,601	6,976	8,500
Dare	5,405	5,935	6,995	7,800
Gates	9,555	9,254	8,524	8,200
Hertford	21,453	22,718	23,529	22,500
Hyde	6,479	5,765	5,571	5,600
Martin	27,938	27,139	24,730	24,000
New Hanover	63,272	71,742	82,996	92,100
Onslow	42,047	86,208	103,126	94,200
Pamlico	9,903	9,850	9,467	9,400
Pasquotank	24,347	25,630	26,824	27,100
Pender	18,423	18,508	18,149	18,800
Perquimans	9,602	9,178	8,351	8,300
Pitt	63,789	69,942	73,900	73,500
Tyrrell	5,048	4,520	3,806	3,700
Washington	13,180	13,488	14,038	13,600
TOTAL	499,188	570,658	609,087	620,300
SOUTH CAROLINA				
Beaufort	26,983	44,187	51,136	54,900
Berkeley	30,251	38,196	56,199	58,200
Charleston	164,856	216,382	247,650	256,200
Colleton	29,242	27,816	27,622	28,300
Georgetown	31,762	34,798	33,500	35,400
Horry	59,820	68,247	69,982	79,000
Jasper	10,995	12,237	11,985	12,000
TOTAL	352,919	441,863	497,984	524,000
GEORGIA				
Bryan	5,965	6,226	6,539	7,300
Camden	7,322	9,975	11,334	12,900
Charlton	4,821	5,313	5,680	6,200
Chatham	151,481	188,299	187,816	179,700
Glynn	29,046	41,954	50,529	50,900
Liberty	8,444	14,487	17,569	17,700
McIntosh	6,008	6,364	7,371	8,200
TOTAL	213,087	272,618	286,837	282,900
FLORIDA				
Brevard	23,653	111,435	230,006	229,400
Broward	83,933	333,946	620,100	738,600
Dade	495,084	935,047	1,267,792	1,367,100
Duval	304,029	455,411	528,865	547,800
Flagler	3,367	4,566	4,454	5,400
Indian River	11,872	25,309	35,992	40,800
Martin	7,807	16,932	28,035	36,800
Nassau	12,811	17,189	20,626	24,400
Palm Beach	114,688	228,106	348,993	483,000
St. Johns	24,998	30,034	31,035	34,700
St. Lucie	20,180	39,294	50,836	57,700
Volusia	74,229	125,319	169,487	191,200
TOTAL	1,176,651	2,322,588	3,336,221	3,675,900

is that the central business district is rapidly declining in importance. Population, commercial activities, and industry have been decentralizing for several decades. The modern shopping centers which are so prevalent today did not come into existence until after the termination of World War II. Manufacturing has largely moved from the central city to new locations in the outskirts of metropolitan centers or even in isolated rural areas.

Two types of urban structures are evolving: One has as the main street the perimeter highway that connects a series of the major shopping centers. Over the last few years, large numbers of apartment complexes have come into existence near these perimeter highways. The other new main street of America is the interstate or other multi-lane expressway that stretches for hundreds of miles with attached nodes of residential development, manu-

facturing establishments, shopping centers, major recreational facilities, medical complexes, transportation centers, and the like, forming a strip city.

The most spectacular of this latter type is the megalopolis of the eastern seaboard that joins cities from New Hampshire to Virginia into an amazing urban complex. The scholar, Jean Gottmann, who popularized the concept Megalopolis in his book by this name stated that this new urban region brought rural and urban together into an integrated whole, "In this gradual symbiosis two seemingly conflicting trends have worked together: urban people and activities have taken on more rural aspects and traditionally rural pursuits have acquired urban characteristics. Some sectors of an urbanized region have come to look the way rural countryside used to while districts specializing in agricultural production have begun to resemble built-up suburbs. The whole pattern of land use has changed rapidly" (Gottmann, 1961:217).

More recently, another major megalopolis has come into existence along the east Florida coast that promises to incorporate the entire Florida peninsula. Today, a narrow band of urban development extends the length of the state from Miami to Jacksonville.

As yet largely unaffected by this trend have been the coastal areas of Georgia, South Carolina, and North Carolina. Projections of past trends in population growth do not indicate the urbanization of this section of the Atlantic coast. (See Figure 2). Yet, trends other than past population growth would indicate that the megalopolis of the northeast and that of Florida will eventually merge into a gigantic urban complex extending nearly 2,000 miles.

The availability of land, water, and a mild climate provide the basis for such a development. The final

1. Metropolitan Belt
   1.a. Atlantic Seaboard
   1.b. Lower Great Lakes
2. California Region
3. Florida Peninsula
4. Gulf Coast
5. East Central Texas—Red River
6. Southern Piedmont
7. North Georgia—South East Tennessee
8. Puget Sound
9. Twin Cities Region
10. Colorado Piedmont
11. Saint Louis
12. Metropolitan Arizona
13. Willamette Valley
14. Central Oklahoma—Arkansas Valley
15. Missouri—Kaw Valley
16. North Alabama
17. Blue Grass
18. Southern Coastal Plain
19. Salt Lake Valley
20. Central Illinois
21. Nashville Region
22. East Tennessee
23. Oahu Island
24. Memphis
25. El Paso—Ciudad Juárez

Based on 2-child family projection

FIGURE 2.—Urban regions: year 2000. Source: Pickard, 1972: 143.

catalyst may be the interstates and other expressways which fuse Florida and the northeast into a major main street of the United States.

The emergence of this new entity comes into sharper focus when one reflects that early in the present century before the appearance of the automobile, people fulfilled their needs for goods and services within walking distance of their homes. Homes were located near the place of employment in order that the journey to work could be minimal. Neighborhood schools, grocery stores, churches, plus the local physician made it possible for all to live a rather complete life without leaving the small community. The locality was a functioning social system to which individuals had a strong identity.

The pattern today is much different. Most residential areas have few, at times none, of the services demanded. People go to one locality for medical services, another to schools, still another for groceries, and perhaps a more distant location to purchase clothes, furniture, or an automobile. The automobile has become a necessary ingredient of daily life in the United States. An increasing percentage of the population has two or more automobiles that are continuously in use. The location of goods and services brings patterns of life in which each person tends to travel within an increasingly larger area. Outlook and use of space tends to be more regional than tied to a specific locality.

There are no strong loyalties to a given establishment and a new shopping center can rapidly disrupt existing patterns. Existing trade and service patterns are altered with the construction of modern highways. The interstate system is new and some portions are not complete in the South Atlantic coastal area. With the passage of time, factories, new stores, and services will locate along expressways. These establishments will inevitably provide so much competition that some more isolated businesses will be abandoned. The trend is for more people to spend more time on the highways in satisfying their daily needs.

CHANGING PROBLEMS OF WASTE DISPOSAL IN MEGALOPOLIS

The emerging megalopolis has made dysfunctional the political subdivisions that were largely created during the 19th century. The central city was considered the center of a region with its business nucleus as the "heart." A hierarchical web of relationships bound the metropolis, its suburbs, satellite towns, and rural hinterland into a functioning whole. Each part tended to have its own political identity (Gottmann, 1961:736). The division of responsibilities among state, county, cities, and other minor political subdivisions gave a system that rather effectively provided needed functions.

The unplanned, urban sprawl that has accompanied the development of megalopolis and other urban regions has resulted in one problem with which existing civil divisions were not prepared to cope: maintenance of a pure water source. The water supply depends upon cooperation across many political boundaries. Public health demands services that are increasingly difficult for political units based upon an old urban hierarchical structure to furnish. New collective solutions are needed in many areas but in none more important than the protection and utilization of water resources (Gottmann, 1961: 376–377).

An examination of the changing practices in the disposal of solid and liquid wastes reflects the need as urbanization progresses for political units that can provide collective means of household sanitation as a substitute for traditional, individualistic ones. Even today along the more sparsely populated sections of the South Atlantic States, it is necessary for individuals to fulfill sanitation needs on an individualistic basis. In the modern city a modern sewerage system safely disposes of large quantities of liquid and organic wastes. The periodic rounds of the garbage collector gives an easy way for individuals to discard waste papers, magazines, and a large variety of containers.

Historically, the situation was much different for the person living in isolation. Food wastes were fed to chickens, hogs, and other animals. Papers and other inflammable materials were burned. Tin cans, bottles, and other such materials were thrown into a family trash heap away from the house. Periodically, these latter materials were hauled away and dumped into streams, gullies, or flatlands draining into the estuaries. Human wastes were deposited in the old-fashioned privy or pit toilet. This system of sanitation was based on individual efforts. Even today, sewage lines, garbage collection routes, and the like are not economically feasible in a sparsely settled rural political subdivision with a small tax base.

The expansion of existing metropolitan areas and the growth of smaller population centers into cities forces collective solutions to sanitation problems. In the interim between individualistic and collective solutions, there is a period in which the risks of water pollution are very great. Isolated vacation homes along the beaches and estuaries create special problems. These clusters of homes have no collective solutions to sanitation problems. Often raw sewage is dumped directly into streams. Household trash is

dumped into the edge of a stream to be carried off by the next tide. These practices are often continued in some sizeable towns and villages in spite of health regulations prohibiting such practices. A lone county sanitarian may not have sufficient political clout to stop such practices. Those reared in a rural milieu are accustomed to these traditional practices and do not view them as a threat to health and the environment. Also, many communities are inhabited by people with low incomes who do not have the financial resources to pay taxes sufficiently large to develop sanitary sewage or garbage collection systems. Consequently, these people are often content to continue with the present system.

Answers to questions about other solutions show that a large portion of these people living in isolation believe it would be an infringement on their freedom to have a collective system of waste disposal forced upon them, especially if such a system meant an increase in taxes or a charge for the service.

Collective solutions to many problems may be essential and can only be furnished by new political entities. Yet, individuals will resist the changes. For them, traditional solutions are deemed preferable. Others do not want to see civil subdivisions give up present function and responsibilities. Especially reluctant to see changes are those with a vested interest in the status quo.

The human value system does not necessarily welcome changes that are both needed and inevitable. The response applies to individuals, corporations, and industries.

NEW LIFE STYLES AND WATER POLLUTION

The changing urban structure is accompanied by many changes in lifestyles that can have a great impact upon the estuaries of the nation. In our affluent society there has been the widespread diffusion of many of the material conveniences of human life as the process of urbanization has developed. This affluency has been made possible by the industrialization of the United States and of many other countries. Full employment and economic prosperity have made it possible for automobiles, air conditioning, television, refrigerators, and many other appliances and manufactured products to be possessed by a very large percentage of the United States' population including those who are classed as living in poverty. Most live in houses with modern plumbing and fully-equipped kitchens that protect the family from the rigors of the elements.

Much more important than the simple possession of these material things is the way in which they are used. New lifestyles are coming into existence that affect man's relationship to the environment. A high protein diet, for example, based upon the consumption of beef results in much more land being used to provide food than was true in the past. The direct consumption of potatoes, wheat products, and other starches has steadily declined. Through the years automotive transportation has replaced pedestrian travel and public transportation.

Affluency has become so much a characteristic of American life that it has lost its status value. People today with much more leisure time than existed previously are adopting new lifestyles that have many of the attributes of an old agrarian society. These new lifestyles result in demands for beaches, vacation homes, extensive travel, backpacking, and other forms of outdoor recreation. Dining out and the search for other forms of recreation keeps large numbers of people on the highways.

A focus for many of these activities is along the estuaries of the eastern United States. Residents of the large metropolises throng to the more popular public recreational centers along the rivers, bays, and beaches. Extensive camping and other outdoor activities may destroy the ground cover. Campfires and the haphazard disposal of the debris by the participants of outdoor recreation litter the countrysides. Roads and trails for the increasingly popular four-wheeled vehicles, trail bikes, and dune buggies scar the land.

American society today seems possessed by a desire to escape from affluency and return increasingly to nature. The call to nature has resulted, at times, in the destruction of forests and protective dunes. The channelization of streams, the construction of roads and other recreational and vacation facilities have drastically altered the environment in many areas. Population growth is but one factor in the utilization of these natural resources. New lifestyles are placing new demands upon the natural resources. Obviously, any change in the environment of the drainage areas is going to have an impact upon the water in the estuaries (See Ronald G. Ridker, 1972: 17–33).

DEMOGRAPHIC FACTORS AND NEW LIFE STYLES

Not everybody in the United States follows the same lifestyle. Great differences exist between isolated rural areas, the ghettos of the large cities, retirement villages in Florida, and the suburbs of Connecticut. Even within a given community there may be several principal lifestyles followed by various segments of the population. Style of life may be

considered as the way in which material possessions are used. These patterns of consumption vary among status groups in a community. For example, an automobile may be the source of livelihood for one group of the population, a means of transportation to work for another, and a vehicle for recreational purposes only for still another. These patterns of behavior tend to form configurations which are followed by all within a given group of the population.

During the 1950's there was the stereotype of the suburban family, a couple with four or five children, with its station wagon, residing in a split-level house. The lifestyle of this group would have been much different from that of the factory worker with a pleasure automobile, who took the bus to work while his wife stayed home in a crowded tenement dwelling.

A number of trends can be discerned from demographic and other data that are having a great impact upon the lifestyles in the United States. Some of these trends are developing more rapidly in the coastal areas than in other sections of the nation.

Leisure Time

One of the more important of these developments for the estuarine areas has been the shorter workweek for those in the labor force, resulting in more time for leisure. For more than a century man has increasingly had more of his day freed from economic pursuits which increases his opportunity to engage in recreational and other activities. The classic work describing this transition was published by Sebastian de Grazia in 1962 under the title, "Of Time, Work, and Leisure." De Grazia points out several changes that have reduced the time man spends in economic pursuits.

The first of these is that people in the United States enter the labor force at a later age than they previously did. In the past, adolescents of 12 or 14 often were full-time workers. Various labor laws and increasing years of education have resulted in people entering the labor force at an older age.

Second, changing customs and laws have resulted in people retiring at the age of perhaps 60 or 65. Retirement was almost unknown in the past. Today almost all workers may expect voluntary or involuntary retirement in their 60's. Further, increasing life expectancy in the United States has resulted in a much larger percentage of all people born eventually reaching the retirement age and having several years of life outside the labor force.

In addition to the delayed entry into the labor force and the withdrawal from it two other developments have occurred that give those in the active productive ages much more leisure time. The first of these is that most employers now make provision for vacations. The paid vacation is a relatively recent phenomenon. "As late as the 1920's only a small number of wage earners had paid vacations. Among salaried workers the paid vacation was more common" (De Grazia, 1964:59–60). Today, vacations, holidays, and sick leaves for the average worker are a fringe benefit that reduces the number of hours the average person works per year by at least 15 days.

Even more spectacular has been the decline in the number of hours that people work. De Grazia estimates that in 1859 the average agricultural worker put in 72 hours a week and those in non-agriculture industries 65.7 hours every week. After this date there have been steady declines in the number of hours that people work. By 1940 it was estimated that those in non-agriculture put in 54.6 hours. By 1960 these figures on the length of the average work week had dropped to 38.0 hours in non-agriculture and 44 in agriculture, an average of 38.5 for all workers (1962:420). The declines since this date have been more modest. It has been estimated that the average workweek had dropped to 37 in 1970. He projects it will further decline to 35 hours by 1980 (De Grazia, 1968:114).

These estimates are for the nation as a whole. The actual number of hours worked might differ somewhat in the eastern United States, but the trend is unmistakeable. People today have a greater percentage of their life outside the labor force and while employed work on the average much less than a generation or so ago. This shorter workweek provides a basis for new lifestyles that would not have been possible in the past when the average employee had little time for anything other than meals and sleeping in addition to his work. Free time for recreation was almost unknown. The activities of the entire family are influenced by this new work schedule which permits all members of the family to spend time outside the home.

Retirement

The lifestyles of retired people are much different from those of young adults. Generally, older people are more sedentary and consume less than those in the prime of life. Increasing life expectancy has resulted in a tremendous increase in the number of people above the age of 65 in the United States. In 1950 there were 12,397,000 people above the age of 65 representing 8.1 percent of the total population. This number increased dramatically to 19,972,000 in 1970 and to 21,815,000 as of July 1, 1974. Today 10.3 percent of the nation's inhabitants are above

the age of 65 compared with 9.8 percent in 1970 and 9.2 percent in 1960.

Social security and other retirement plans provide a constant source of income for an increasing percentage of the elderly. Many of these individuals are migrating to coastal sections of the country considered to have a pleasant climate. The vicinity of St. Petersburg, Fla., is widely known as a retirement haven. Approximately 30 percent of the population of several counties in the vicinity of St. Petersburg is above the age of 65 years. Even more striking however, is that 48.8 percent of the Miami Beach population is above the age of 65. Other coastal cities of Florida also are the homes of many retired persons.

A special tabulation of the changing number of people above the age of 65 years residing in the estuarine counties, starting with Broward County, immediately north of Dade in which Miami is located, and extending to the Canadian border, shows a great increase in the number of elderly in recent years.

These coastal counties in 1950 had 2,082,463 residents above the age of 65, but by 1970 this number had increased to 3,569,388, a growth of 71.4 percent. By contrast, the increase in the number of elderly in the country as a whole was significantly less for the period, 61.1 percent.

Table 2 presents statistics on the changes in the number of old people in the eastern seaboard counties, by states. It may be noted that the rate of increase in the population above the age of 65 was below the national average in the coastal counties of Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut to the north, but only North Carolina among the more southern group of states. Most spectacular is the increase of over 400 percent in the selected Florida counties during this 20-year period.

The percentage of the total population of all the eastern seaboard counties above the age of 65 tends to be less than the national average. This finding is a consequence of a high influx of young people in a growing population and will change as those in the productive ages enter retirement, unless the total population continues to increase rapidly through the immigration of young workers.

The trend seems unmistakable for those with financial means to move to warmer coastal areas upon retirement. The small family pattern that has emerged in recent decades coupled with mobility of young people means that the family ties are not as likely to hold a person to the community in which he spent his productive years. Further, substantial growth in the number of people retiring to the southern estuarine counties may be expected. This migration will probably be more directed to larger communities with relatively complete medical and service facilities.

Table 2.—Population 65 years old and over in the estuarine counties of the Eastern Seaboard, 1950–1970

	1950 Number	%	1960 Number	%	1970 Number	%
Maine	47,163	11.2	53,695	12.2	57,849	12.4
New Hampshire	7,931	11.3	9,676	9.8	12,148	8.7
Massachusetts	279,477	11.5	290,850	11.5	334,058	11.7
Rhode Island	70,418	8.9	89,540	10.4	103,932	10.9
Connecticut	112,775	8.9	154,045	9.7	181,267	9.6
New York	823,932	7.9	1,162,666	9.9	1,388,261	11.4
New Jersey	323,957	7.9	461,088	9.0	572,136	9.7
Virginia	101,397	7.3	143,663	7.3	190,587	6.5
Maryland	140,950	7.6	171,749	7.2	128,183	4.3
Delaware	26,320	8.3	35,745	8.0	43,833	8.0
North Carolina	29,002	5.8	37,151	6.5	46,581	7.7
South Carolina	16,745	4.7	22,297	5.0	29,132	5.8
Georgia	12,353	5.8	17,278	6.3	22,329	7.8
Florida	90,043	7.7	234,382	10.0	459,082	13.8
TOTAL	2,082,463	8.2	2,892,824	9.4	3,569,388	10.0

Second Homes

A preoccupation with the growth of population has tended to detract attention from a number of extremely important demographic trends. One of these developments is the proclivity of Americans over the last few years to acquire a second home. These dwellings are generally in the more isolated rural areas where one can enjoy the beauties of nature. The construction of these houses often has very serious ramifications not just for the environment but the economic stability of an area. Often those constructing vacation homes are not restricted by any construction codes or by regulations for disposal of human wastes. Also, many are located in the submarginal areas that should be zoned for forestry or recreation with no residential construction permitted.

One of the most desirable locations for vacation homes in the minds of many people is along the beaches and the estuaries of the eastern seaboard. Of course, other individuals express a preference for the mountains. Regardless of the relative attraction of the mountains or the beaches, a large percentage of the population wants to escape at least periodically, from city life. Beach property has tended to advance manyfold in price during recent years. The increase in the cost of beach property is in itself an indication of growing demands for such sites for a second home.

A special report of the census reveals that 2.9 percent of families in the United States had a second

Table 3.—Second homes and seasonal housing units, estuarine counties of the Eastern Seaboard, 1970

	Occupied Housing Units			Seasonal Housing Units		
	Total Number	Number with Second Home	Percent with Second Home	Total Number	Percent of all Housing Units	State Total Units Held Occasional Use
Maine	146,635	15,672	10.7	35,431	17.6	6,486
New Hampshire	41,677	3,153	7.6	8,274	15.6	3,037
Massachusetts	901,766	56,960	6.3	43,218	4.3	11,611
Rhode Island	291,965	13,337	4.6	9,884	3.1	1,687
Connecticut	577,936	26,146	4.5	7,886	1.3	6,615
New York	4,232,501	189,763	4.5	51,846	1.2	58,186
New Jersey	1,836,689	85,240	4.6	70,506	3.6	21,490
Virginia	864,091	33,885	3.9	4,832	0.5	19,032
Maryland	883,615	28,169	3.2	12,494	1.3	7,974
Delaware	164,804	9,517	5.8	5,222	2.9	1,273
North Carolina	171,543	6,988	4.1	8,052	5.0	13,372
South Carolina	134,430	616,695	5.0	6,938	3.4	8,695
Georgia	86,189	3,764	4.4	509	0.5	12,154
Florida	1,123,478	63,794	5.7	19,389	1.5	46,561
TOTAL	11,457,319	543,083	4.7	284,481	6.2	218,173

home in 1967. This number increased dramatically during the next three years and the 1970 Census of Population reported that 2,890,000 families, or 4.6 percent of the total, had a second home in 1970. The construction of these second homes proceeded at a very rapid pace until about 1973 when the rate of construction declined. Many of these new second homes are a part of large developments in mountain and resort areas, but especially, in some of the more attractive beach areas. No accurate statistics are readily available on the extent of these recent developments.

One indication of the location of these second homes may be obtained from the Census of Housing. These reports show the number of homes in each county classed as seasonal. These figures underestimate the number of vacation homes inasmuch as the census has a separate category for the dwellings held of occasional use. The number in this latter category is not presented by counties. The number of seasonal homes in the estuarine counties (see Table 3) is therefore, the best index available of the location of second homes. Although admittedly incomplete, these statistics reflect the areas in which such dwellings are concentrated.

Two notable concentrations of such houses are in two counties of New Jersey. Cape May had 24,817 such structures and Ocean County had 29,851. Most of these dwellings are used by individuals residing outside the counties because only 1,254 of the families in Cape May reported owning a second home in 1970 and the figure for Ocean County was but 3,245. Another concentration is in Barnstable County, Mass., (Cape Cod) which reported 21,524 seasonal homes. Relatively few were reported for the coastal areas of Georgia, Virginia, North Carolina, and South Carolina. Nevertheless, it is known that several land developments have brought about such increases the last few years.

The percentage of the population of the estuarine counties with a second home is presented in Table 3. The proportion of the population owning a second home in these counties does not differ greatly from the national average, and is most pronounced in the most northern coastal states of Maine, New Hampshire, and Vermont. Florida and Delaware are also above the national average, but to a lesser extent.

Although the county statistics are not available on the number of dwellings held for occasional use, they are for the states as a whole. An unknown portion of these housing units are along the estuaries. It may be noted in Table 3 that, relative to the total population of the states, these houses are more characteristic of the southern states. It would appear that the second homes in New England tend to be held for use during the summer months but for year-round use in the South.

Nationally, this upsurge in the number of vacation homes indicates a trend that may be predicted to continue if economic conditions permit. The development of second homes will have a great impact upon the areas in which they are located.

Commuting

The vast majority of the population of the United States lives in the metropolitan areas of the nation. In these areas almost inevitably the home and work are separated. This journey to work is certainly a factor in daily existence of many people, but the phenomenon of commuting is much more complex than often is realized. For one thing, there are large numbers of households in which both the husband

and wife are employed outside the home. As a consequence, both are engaged in this journey to work. The pattern is not all that crucial at the present time in estuarine counties that are non-metropolitan, but indications are that it will become more important in the future.

Several studies have been made in recent years of the residential preferences in the United States. A Gallup poll in 1966 reported that 49 percent of respondents would rather live in a small town or rural area than a larger community. Two years later this figure had increased to 56 percent (Zuiches and Fuguitt, 1972: 622).

A survey in 1971 for the Commission on Population Growth and the American Future indicated that 64 percent of the U.S. population preferred to live in small towns and rural areas (1972:34). Investigations in Wisconsin add another dimension to these findings. Wisconsin residents also prefer to live in small towns and rural places, but most of these individuals want to be within commuting distance of major metropolitan centers (Zuiches and Fuguitt, 1972:626). Apparently, the person living within 30 miles of a large city can enjoy the quiet and tranquility of the countryside, but for the satisfaction of his needs, he is able to get to the large city in a short period of time. In other words, the individual residing within the commuting area of a major metropolis sees the opportunity for enjoying the advantages of both the rural and the urban environments.

The survey by Zuiches and Fuguitt also presented statistics that most people do prefer life in a residential area about the same size in which they were reared. This finding is especially true for those reared on the farm. As the size of a center in which a person was reared increases, however, a definite tendency is noted to be less satisfied with the urban areas and for people to express a desire for a more rural setting (1972:627).

Of course, a related question will be whether or not people move in terms of these preferences. A public opinion survey indicates that a relatively large percentage of the population believes that they will actually change their place of residence according to these preferences or that they reside in a desired location. Maize and Rawlings report that 80 percent of the respondents in a survey were either living in the preferred location or expected to eventually move to such a place (1972:608). Such a tendency is much more pronounced as the size of the center increases. Rather interestingly, whites are much more likely to move in terms of these aspirations than are blacks. In fact, urban blacks tend to be much more satisfied with their residential area than whites. Maize and Rawlings suggest that a reason for this is that many blacks were reared in rural areas where life was not kind to them and only in the cities have they found a more pleasant life than the rural setting of their childhood. A move back to the rural areas might be viewed as a step backward. (1972:607).

If these generalizations are valid for the southern coastal areas, they would explain why these areas have not been experiencing as rapid population growth as other coastal sections of the nation. Large numbers of southern blacks have moved to the cities of the nation, especially to northern ones during the past half century. This out migration has brought a sizeable decline in the population of some of the more rural coastal counties. In the near future, these counties will probably be able to experience rapid growth only through the immigration of whites who are searching a small rural milieu.

Certainly, the basic attitudinal dispositions exist that can bring a shift of residence toward the smaller towns and rural areas. Relatively few economic opportunities exist in sparsely settled areas. Thus, the incidence of commuting to work may be expected to grow.

One index of the extent of commuting is the proportion of workers whose place of employment is outside the county of residence. The Census of Population reports that in 1970, 17.8 percent of all workers traveled outside the county where they lived to work. This rate of commuting is lower in the western than the eastern states, no doubt in part because western counties tend to be larger. Nevertheless, it is significant that the highest commuting rates were in the states along the eastern seaboard. In Virginia, for example, 39.9 percent of all workers leave the county of residence to work. Next highest is Maryland with 36.7 percent, followed by New Jersey and New York with 32.7 and 31.8 respectively. Large metropolitan centers such as Washington, D.C., and New York City are the places of employment, but not of residence, of large numbers of people.

The data in Table 4 show that the percent of the population working outside the county of residence in the estuarine counties of the eastern seaboard was 50 percent in 1970, a substantial increase from the 37.8 percent in 1960. No tabulations were made on the extent of inward commuting, which is substantial in some areas.

Further, it may be noted that there has been a great increase in the number of people working outside the home county, from 29.7 in 1960 to 36.4 in 1970 (see Table 4). The general pattern has been for in-county employment to increase much less

Table 4.—Commuting in the estuarine counties of the Eastern Seaboard, 1960–1970

	Workers Residing in Area 1960		Workers Residing in Area 1970		Percent Change in Number of Workers 1960–1970	
	Number	Percent Working Outside County	Number	Percent Working Outside County	In-County	Out-of-County
Maine	144,321	11.8	164,286	13.7	11.5	31.6
New Hampshire	36,366	34.4	49,753	43.9	16.9	74.8
Massachusetts	954,803	23.8	1,051,978	29.5	2.0	36.6
Rhode Island	314,117	21.1	362,305	23.6	11.6	29.3
Connecticut	591,889	11.3	700,545	14.7	13.8	54.1
New York	4,360,154	39.3	4,461,025	44.5	6.4	15.7
New Jersey	1,838,624	30.0	2,129,583	34.7	8.0	34.1
Virginia	725,562	42.8	1,129,096	46.8	44.6	70.3
Maryland	833,353	31.6	1,588,326	59.1	14.1	256.1
Delaware	156,030	7.9	194,922	11.7	19.7	85.9
North Carolina	189,133	10.6	223,783	18.3	8.1	105.1
South Carolina	140,030	7.1	171,931	11.6	16.8	100.8
Georgia	93,243	3.7	95,531	5.6	0.5	53.1
Florida	802,332	5.0	1,150,296	6.6	40.9	90.8
TOTAL	11,179,957	29.7	13,473,360	36.4	12.8	47.7

rapidly than out-of-county employment. If present trends continue, commuting will involve a greater number of people than employment within the county of residence.

Women in Labor Force

One factor in the increase in commuting has been a trend for more and more women to enter the labor force. Large numbers of married women are now working outside the home. When both husband and wife are employed, it is unlikely that they will share the same journey to work. At times their hours differ, but more often, they go in different directions. If they are employed in locations miles apart, then one, if not both, must resort to commuting. The home cannot be near both places of employment.

Furthermore, if both husband and wife work, their income will be more adequate to maintain a suburban lifestyle. With increases in income, people tend to move out from the central city.

Patterns of life for a married couple change when both are employed. The increased participation of married women in work outside the home may be demonstrated by a few statistics. In 1950, only 23.8 percent of married women with husbands present were in the labor force. This figure reached 30.5 percent in 1960, but accelerated after that date to 40.8 percent in 1970 and 41.5 percent in 1972. The figures for the total adult female population show the same trend. In 1950, 31.4 percent of females above the age of 14 were in the labor force. This figure was reported as 43.6 percent in 1972.

Rates of participation in the labor force were not tabulated for the eastern seaboard counties. The same patterns are developing in this area as elsewhere. The total number of females in the labor force for these estuarine counties increased from 4,298,003 in 1960 to 5,546,198 in 1970, an increase of 29 percent. During the same 10-year period, the number of males in the labor force grew from 8,367,066 to 8,951,665, an increase of but 9 percent.

Undoubtedly, the employment of women outside the home is a major factor in the changing lifestyles of the coastal areas. Inasmuch as birth rates are declining, it may be anticipated that an increasing percentage of women would continue to look outside the home for fulfillment. This trend will, of course, be determined by the availability of employment.

Land Use Changes

Nationally, the number of acres in farms has steadily declined since the soil bank program of the 1950's. At the same time, the number of farms continued to decline from the peaks reached early in the century. Meanwhile, the average size of farms has increased. The family farm is giving way to the commercialized enterprise.

The number of farms in the estuarine counties of the eastern seaboard has dropped from 194,448 in 1950 to 72,049 in 1970, a decline of 62.9 percent in only 20 years. (Table 5).

The widely publicized world food crisis will probably result in the expansion of large scale agricultural enterprises along the eastern seaboard. Much of this area, especially along the South Atlantic coast, was at one time abandoned for agricultural purposes with the westward movement of settle-

Table 5.—Number of farms in estuarine counties on the Eastern Seaboard, 1950-1970

	1950	1960	1970	Percent Change		
				1950	1960	1970
Maine	12,075	6,778	2,664	−56.1	−39.0	−21.9
New Hampshire	2,206	1,076	427	−48.7	−39.7	−19.4
Massachusetts	7,899	3,947	2,132	−50.0	−54.0	−27.0
Rhode Island	2,598	1,395	700	−53.7	−50.1	−27.0
Connecticut	6,981	3,464	1,801	−49.6	−52.0	−25.8
New York	17,346	19,503	6,030	−12.4	−30.9	−35.0
New Jersey	17,274	10,790	5,481	−62.5	−50.8	−32.0
Virginia	36,134	19,781	12,255	−54.8	−62.0	−34.0
Maryland	21,426	14,746	10,229	−68.8	−69.4	−48.0
Delaware	7,448	5,208	3,710	−70.0	−71.2	−49.8
North Carolina	34,899	24,731	15,218	−70.8	−61.5	−43.6
South Carolina	18,900	11,645	6,072	−61.6	−52.1	−32.1
Georgia	2,301	1,158	582	−50.3	−50.3	−25.3
Florida	6,961	6,097	4,768	−87.6	−78.2	−68.5
TOTAL	194,448	130,319	72,049	−67.0	−55.3	−37.0

ment. Rice plantations in the lowlands of the Carolinas and Georgia were abandoned long ago. Timber companies presently own very large tracts of land. Other areas such as the Golden Isles off the coast of Georgia became hunting preserves and vacation retreats for wealthy citizens.

Under the demands for increased agricultural production, it is very probable that pressures will be exerted to convert present timberlands back to food production. Large capital investment requirements often result in large scale operations, sometimes referred to as "factories in the field." Indicative of this type of operation is the development by the McLean Corporation of most of Tyrrell County, N.C., into a tremendously large corporation farm of 375,000 acres. With heavy equipment, it is possible to convert this tremendously large acreage into huge agricultural enterprises over a very short period of time. Named First Colony Farms, this operation will have 225,000 acres under cultivation. Most of this land was in timber in 1972. Now it is becoming a factory that will produce corn and soybeans to be fed to cattle and 50,000 hogs.

The concentration of land ownership simplifies the creation of this kind of enterprise. The plea that people throughout the world are starving to death and that the citizens of the United States are threatened with imminent starvation makes it extremely difficult to halt or control these developments. Low agricultural yield in 1974 for the Midwest has been interpreted as a harbinger of worldwide shortages in the future. Continued pressure to open new areas of the United States to agricultural production is a likely consequence.

The Southern Atlantic States provide one of the best opportunities for large corporations to develop factories in the field in the shortest possible time. The availability of water and the natural fertility of soil that has remained fallow for many years provide the potential for tremendous agricultural yields.

Obviously, the draining of swamps and the destruction of ground cover would drastically alter the ecology of the area within a short time. The impact of the runoff on the estuaries would be quite dramatic.

Only part of the land taken out of agriculture has been converted to highways, urban residential areas, industrial development, and the like. Such diverse uses receive much attention in the press. But a significant portion of the lands that were in cropland are not used for forestry and grazing. Forest lands in the United States have increased substantially over recent decades. No tabulations were made of the acreage in the estuarine counties that has returned to forests during recent years. Woodland not in farms increased from 127,358 thousand acres in 1959 to 146,733 thousand acres in 1969 for the states along the eastern seaboard. Of these coastal states, only Florida failed to register an increase in its forested area during the period.

At the other extreme, there are developments which significantly change the use of the land. New highways, shopping centers, and the like are known to all. However, one change has been largely ignored, and accurate statistics of the phenomenon do not exist. The average residential lot has steadily increased in size with suburban growth. The single family urban dwelling of two generations ago occupied a relatively small space. Lot size was adapted to the pedestrian. Today, a new single family dwelling in the suburbs requires a much larger space. One reason for this change is that zoning regulations often specify that the new residential lot be much larger than was true in the past (Gottman and Harper, 1967:87).

Along the eastern seaboard the future will probably bring an increase in the amount of land under cultivation, a decline in the forested area, and an increase in the urban type usages of the land that result in great ecological changes. Such changes will undoubtedly have a significant impact on the water in the estuaries.

New Living Arrangements

The number of dwelling units in the United States has been increasing much more rapidly than the population. The number of residential units in the counties of the eastern seaboard, for example, grew

from 6,193,753 in 1950 to 12,078,450 in 1970, an increase of 98.8 percent. The residential unit tends to be a more important entity than the individual in terms of utilization of resources. Each house requires plumbing, roads, utilities, lot space, and a variety of services. Obviously, there has been a decline in the average number of people per dwelling unit. Several factors are involved in this change:

1. During the depression years and earlier, families tended to often share the same residence. Married children were, especially, inclined to live with parents until financial security was reached. Full employment and prosperity have permitted most couples to have separate dwellings.

2. Another important factor is the increase in one-person households. In the past, the individual living alone was generally an elderly widow. A shift has taken place in recent years. Young employed adults, both male and female, seek a separate dwelling unit until marriage. Even among the college students, there has been a rapid transition to the apartment and away from the dormitory. The demand is for housing for individuals, not families.

3. Much residential construction during the last decade has been of apartment complexes. These units cater to the individual desiring to establish a one-person household. In 1960, 237,000 structures were built with three or more housing units. By 1970, this figure had increased to 606,000. Only two years later in 1972, 646,000 housing structures with three units or more were started. Apartment construction has multiplied rapidly, but each unit tends to have a small number of occupants on the average. Some apartment-style construction has been outside the cities in former open country areas, and has created environmental problems.

4. Yet another dramatic change in living arrangements has been the growing popularity of the mobile home. The shipment of mobile homes increased from 216,000 in 1965 to 576,000 in 1972. The mobile home has become especially popular in rural areas of the South. Financing has been easy to secure for those owning land. Few consider them as a permanent solution to housing needs. However, in a short time a person can have one installed and move into it, often without satisfactory provision for disposing of household effluent. Many mobile home parks have been established along the estuaries of the southern United States with raw sewage draining directly into the streams.

In addition to the mobile homes that serve as a regular residence, there are smaller units used by vacationers to camp in great numbers in trailer parks throughout the nation.

THE QUEST FOR QUALITY OF LIFE

For the last four or five years, everyone seems to have been seeking some elusive goal now designated as quality of life. The phrase was not a part of the vernacular a very few years ago. Now suddenly it is very widely used. Many scholars are now writing on the topic. Most of these essays are non-scientific and describe the kind of situation that the individual feels is ideal without any attempt to really specify the content of the quality of life. At one time, quality of life represented the goal of attaining trappings of affluence: automobiles, refrigerators, television sets, and other material things.

There is considerable evidence today that people are no longer as oriented toward material things. New lifestyles are evolving, that is, the manner in which material things are utilized. For example, an automobile may be used simply as a means of transportation to and from work, or it can be a source of livelihood, a status symbol, or even a major item of recreation. Today in our affluent society all tend to possess a vast array of material goods. The non-material life patterns, consequently, are becoming increasingly important.

The quality of life that is being sought has great ramifications for water pollution. The desire to visit the wide-open spaces, to go fishing, backpacking, camping, and the like are bringing great numbers of people into the areas that were uninhabited just a few years ago. As a consequence, there is really very little land in the United States that is not used for some purposes, whereas in the past, even around urban concentrations, there were still large tracts of lands that no one visited.

Indicative of the attempt to find a new style of life is the number of people who fish and hunt. The total number of fishing licenses issued nationally in 1950 was 15,338,000. By 1971, this figure had increased to 32,384,000. The number of hunting licenses sold jumped from 12,638,000 to 22,912,000 during the same 11-year period.

The number of outboard motors in use increased from 2,811,000 in 1950 to 7,400,000 in 1972. Outdoor recreation is a part of the desired quality of life of growing percentages of the population. It is a part of the general desire to live closer to nature.

Not to be ignored in this process of seeking a new quality of life are the amenities provided exclusively by urban living in the past. Early in the present century, only in the city could a person find modern bathrooms, running water in the kitchen, and electricity which made it possible to have refrigerators, electric lights, radios, and many of the other con-

veniences of life. These were undoubtedly one of the features of urban life that brought many to the city who could have stayed in the rural areas practicing a subsistence agriculture or living during the retirement years. Through the spread of electricity into even the remote sections of the United States, the rural resident can have all of these advantages of urban life. As a consequence, migration to a rural area does not involve a loss of these modern conveniences. In the affluent society, they provide a base of material comfort that is universally available in the United States. Increase in the quality of life is almost always followed by an even greater increase in the use of water and volume of waste materials.

Other amenities in the new style of living are coming into existence. One of the most important of these is climate. Ullman noted almost a generation ago that "for the first time in the world's history, pleasant living conditions—amenities—instead of more narrowly defined economic advantages are becoming the sparks that generate significant population increase, particularly in the United States" (1954:119). Ullman insists that the suburban movement reflects this search for a more pleasant life. Between 1940 and 1950, the suburban population of the nation increased 35 percent as compared with 13 percent inside the city limits and only 6 percent elsewhere. At the same time, other areas, largely coastal, with pleasant climate experienced a tremendous upsurge in their population. In the decade of the 40's the population of California increased 53 percent, Arizona 50 percent, and Florida 46 percent. Two other coastal states that also experienced this rather rapid rate of growth were Oregon and Washington, whose populations increased 39 and 37 percent respectively. Ullman considered climate a major factor and believed that most people would prefer to live in an area where the temperature averaged 70 degrees the year round. This "Mediterranean" type climate exists in Florida and California.

Even industry that is freed by modern transportation and communications from the inner city has viewed the climate as a major element in building new industrial establishments. Climate shows no signs of declining in importance. We may anticipate a continued movement of the population toward the coastal areas. The only large, undeveloped coastal area remaining in the United States is that of the southeast states.

CONCLUSIONS AND RECOMMENDATIONS

In contrast to the situation in western portions of the United States, the eastern seaboard has a relatively ample supply of water. Evidence is accumulating that water will be the natural resource that limits human development more than any other throughout the world. Adequate water supply does not mean there will be no problems in regards to this valuable resource. Just as important in many ways as the quantity of water available is its quality.

Industrialization, urbanization, and rapid growth of the population have often been associated with increased water pollution. The theme of this report has been that the changing life patterns of mankind have more influence upon the quality of the water in the estuaries than the mere numbers of people.

Several trends have been enumerated which reflect changing lifestyles in the United States and which must inevitably have some impact upon the estuaries:

1. The population of the United States is rapidly shifting to the coastal areas of the nation, while other sections are being depopulated; especially are people leaving the interior sections of the nation. Approximately one-half of the over 3,000 counties in the United States lose population each decade. At the same time, a new urban structure is evolving. The megalopolis of the northeast, extending from Massachusetts to Virginia, represents an attempt by man to combine elements of rural and urban living. Another megalopolis has been established along the east coast of Florida that promises to eventually encompass the entire peninsula of Florida. Population growth has been slower in the coastal areas of the south Atlantic coast. Indications are that a megalopolis is developing that will extend along the entire eastern seaboard. In the absence of careful planning, the water pollution problems of the northern coastal area may be expected to be duplicated in the South.

2. The trends toward a shorter workweek, paid vacations, late entry, and early exit from the labor force result in people today having much more time for leisure pursuits than was true for past generations. Much of this additional time is devoted to outdoor recreation, travel, and a demand for services on the part of the entire spectrum of social groups in the United States rather than a small leisure class.

3. A third trend in modern society has been the withdrawal of people from the labor force upon retirement in the 60's. Increased life expectancy has resulted in a much larger percentage of the population achieving advanced ages and enjoying several years outside the labor force. These retirees increasingly have a stable income from social security and various pension plans. Large numbers of retirees

are moving from the location where they spent their economically productive years to complete their lives in the coastal areas of the nation, especially those sections where the climate is mild.

4. Before the advent of automotive transportation, workers lived at a location where the journey to work could be minimized. Today, an ever-increasing percentage of the population is commuting daily from homes in the suburbs to employment a considerable distance away. As the journey to work becomes ever greater, dependence on public transportation has declined, and the automobile has become the focus of new lifestyles.

5. The small family pattern, modern household appliances, plus smaller homes have eliminated much of the drudgery of housework. Women, as a consequence, have increasingly sought employment outside the home. Their additional incomes make it possible for families to enjoy a higher level of living than before, which is often manifest in establishing residences away from the central city. Because husband and wife work in different locations, commuting must become a part of their lifestyles.

6. Land use has dramatically shifted along the eastern seaboard over the last 100 years. The number of farms has declined rapidly for decades. Initially, this decline resulted in lands being abandoned for agricultural purposes and becoming reforested. The growth of cities and the construction of highways and other facilities will probably bring a decline in forest acreage. Pressures to produce food for a hungry world may result in much land in the South Atlantic area being converted to large "factories in the field." Huge corporation farms would drastically alter the ecology of an area. Demands also exist to transform lands into public recreational facilities or to retain them as unchanged natural areas.

7. One of the most striking trends in the United States has been the increase in number of dwelling units. One-person households and the disappearance of the doubling-up of families have resulted in a steady decline in the number of people per residential unit. The housing unit tends to be the entity that disrupts the ecology of an area, rather than the number of people per se.

8. A dominant theme in American society today is the quest for a new quality of life. The term has not been adequately defined, but there is an unmistakable desire on the part of many people to follow some of the life patterns that existed when life was much simpler in the rural areas. These new lifestyles are associated with a desire for more contact with nature, not only as a place of residence, but also as a place to spend leisure time.

One of the reports for the Commission on Population Growth and the American Future summarized the trends in the redistribution of the population as follows:

> 1. People are vacating extensive portions of the nation's territory—particularly the middle of the continent—and concentrating along the coasts.
> 2. The United States becomes more and more urban with each passing year; most Americans now reside in metropolitan centers of at least 100,000 inhabitants.
> 3. The structure of these urban settlements is undergoing a gradual metamorphosis; metropolitan areas and their hinterlands are merging into larger constellations to form urban regions.
> 4. Important internal differentiations are taking place within the jurisdictions of metropolises; inside, their population is leveling off or shrinking and changing to nonwhite; in the suburban rings, it is expanding and remaining largely white.
>
> These changes have given rise to national problems concerning the environment, the aesthetic quality of urban and rural life, and racial separation—issues of coping individually and collectively with the process of urbanization. Curtailing national population growth, while helpful in the long run, cannot resolve these problems in the near term (Morrison, 1972:23–24).

The Commission on Population Growth and the American Future strongly recommended that the policies of this nation be built about the concept of population stability rather than growth. The Commission insisted in the long run there must be a population stability because even an infinitesimal rate of population growth cannot continue indefinitely (1972:75–79). It is recognized that population growth may very well continue for some decades, but the Commission insisted that thinking and planning must be based on population stability.

Many people find it difficult to adjust to this concept of stability. Our economy has been based on some inflation as well as population and city growth. Bigger has long been considered better. Rapid population growth accompanied with inflation and industrial expansion has been sufficient to compensate for poor planning. Population stability will result in new homes which are needed only for replacement of those being abandoned. Inflation which assures a profit on manufactured products cannot be continued indefinitely. The pessimistic volume, "The Limits to Growth," written by a group of experts from Massachusetts Institute of Technology (Meadows, et al., 1972) projects global collapse coming as a result of population growth. If equilibrium is not reached in population growth, perhaps through increased pollution, industralization, urbanization, and the destruction of nonrenewable resources, the calamity these authors forecast would come about.

Still, not all present trends will continue. One way to assure a reversal in the direction of change will be the adoption of policies that enforce population

stability plus restrict other forms of development. A situation of population equilibrium will almost undoubtedly result in more careful planning of the location of schools, highways, residential areas, industrial plants, and even agricultural operations.

This planning almost certainly will result in more consideration being given to the natural environment, especially in those areas where unhampered development can lead to greater water pollution.

With this background, three recommendations of the Commission of Population Growth need to be adopted if the estuaries of the nation are to be protected:

> 1. Recognizing that our population cannot grow indefinitely, and appreciating the advantages of moving toward the stabilization of population, the Commission recommends that the nation welcome and plan for a stabilized population (1972:143).
> 2. The Commission recommends that: The federal government develop a set of national population distribution guidelines to serve as a framework for regional, state, and local plans and development;
> Regional, state, and metropolitan-wide governmental authorities take the initiative, in cooperation with local governments, to conduct needed comprehensive planning and action programs to achieve a higher quality of urban development;
> The process of population movement be eased and guided in order to improve access or opportunities now restricted by physical remoteness, immobility, and inadequate skills, information and experience;
> Action be taken to increase freedom in choice of residential location through the elimination of current patterns of racial and economic segregation and their attendant injustices (1972:144).
> 3. To anticipate and guide future urban growth, the Commission recommends comprehensive land-use and public-facility planning on an overall metropolitan and regional scale.
> The Commission recommends that governments exercise greater control over land-use planning and development (1972:144).

Although relevant to the process of water pollution in the estuaries of the eastern seaboard, these recommendations of the population commission are general and apply to the nation as a whole. There are other recommendations that need to be made which are more unique to problems existing in counties along the estuaries of the Atlantic coast. These specific recommendations are as follows:

1. That new legal entities be created whose jurisdiction will be independent of existing political subdivisions. Problems of planning code enforcement must encompass the whole region rather than discreet, competing parts thereof.

2. That intensive demographic and sociological studies be undertaken that will equate changing lifestyles with the new emerging urban structure, the eastern seaboard megalopolis.

3. That these studies by social scientists be integrated with interdisciplinary studies in cooperation with natural scientists in order to better understand the ecological problems of the eastern seaboard.

4. That regional zoning be accomplished which will restrict the use of the land for recommended purposes. Such a zoning plan must necessarily ignore existing political boundaries.

5. That growth along the eastern seaboard be controlled through the construction of a transit system the entire length of the Atlantic seaboard in accordance with plans for the ideal utilization of various zones. Land use and development is a function of the system of transportation.

6. That special studies be made of the South Atlantic coastal area and contrasted with developments along the North Atlantic coast. Such studies are essential if problems that had been generated in the Northeast are not to be duplicated in the South.

7. That regional plans be made for the provision of utilities and, especially, public health facilities for the entire coastal area. Regional building and sanitary codes are needed that cannot be ignored by smaller political divisions.

8. As this is being written, problems of energy, inflation, and unemployment add to the urgency for planning. However, these plans must be based on a sound understanding of the relationship of the immediate situation to both past and long range future developments.

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ESTUARINE ECONOMICS

ECONOMIC ANALYSIS IN THE EVALUATION AND MANAGEMENT OF ESTUARIES

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ABSTRACT

This paper describes an economic-environmental systems model for analyzing estuaries which has been used in Maryland to forecast the quantities and types of waste and residuals which will be generated through the year 1985 for the Chesapeake Bay and each of its major tributaries. The model indicates that the amount of residuals will be a function of the rate and composition of economic development. Consequently, economic development and growth in the region can be expected to generate water quality problems of increasing magnitude for all estuaries in the U.S. Various corrective policy measures are evaluated for dealing with the environmental threat to the quality of estuarine waters. One of the most serious environmental impacts is aesthetic damage and methods are suggested for applying charges for various levels of aesthetic damage in order to encourage improved qualities of economic development.

A national policy on estuarine management would recognize both the economic realities of common property resources and the federal structure which has evolved in U.S. political history. Consequently, a national policy on estuarine management would establish minimum national standards for quality, leaving local authorities to establish higher standards if so desired. However, no economic or political justification can be discovered for permitting local areas to relax environmental standards below those set by federal government. The establishment of higher local standards than those stipulated by federal policy would provide financial and other incentives to improve technology and encourage generators of pollution to internalize external costs. Finally, specific recommendations are made for establishing a national policy for better management of estuaries, which are among our most important natural and environmental resources.

INTRODUCTION

Estuaries are the vital interface between land and water, between oceans and rivers, between ecology and technology, and between the conflicting demands for environmental quality and economic development. Estuaries are the bodies of water over which will be fought the emerging battles for energy production versus conservation and economic growth versus the reduced growth movement. The problem of analyzing and resolving these conflicts will require a more complete understanding of the relationships between man and his environment and the relationships between the social, physical, biological, and earth sciences than has been available in the past.

The accumulation of economic and other reinforcing institutional factors which encourage overuse and mismanagement of estuaries is a growing threat to water quality and biological, ecological balance in the nation's waterways. Environmental economists are attempting to measure, forecast, and analyze these phenomena by developing new types of models based upon tested economic tools combined with materials balance and entropy concepts derived from the physical sciences. Some of these large-scale computer models are now capable of estimating the generation of many individual wastes, residuals, and pollutants over time throughout different parts of the estuary. For example, Table 1, taken from one such study, estimates the gross generation of residual nitrogen generated in each of the 16 major river basins of the Chesapeake Bay by 5-year intervals from 1970 through 1985 (Cumberland and Herzog, forthcoming). This study estimates an average annual growth rate for nitrogen releases of 5.7 percent, but with significant variance between the individual political subdivisions and river basins involved. This annual growth rate, if continued, implies a doubling of the pollution load approximately every 14 years.[1] These projected pollution growth rates underline the urgent need to develop more effective control measures if society is to enjoy benefits of these resources in future generations.

[1] Similar estimates are available in the study for growth of other pollutants, as well as for the accompanying economic development in each of the major river basins which make up the Chesapeake Bay Regional System.

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It is the major point of this paper that current mismanagement of our estuaries results from omissions and inadequacies in the conceptual models and management theories which have been applied to the governance (or more generally, the non-governance) of estuaries. Among the more serious gaps in our models for managing estuaries are: failure to include the lessons of environmental economics; failure to include new interdisciplinary knowledge and concepts such as materials balance and energy-entropy models; failure to use models based upon a total systems approach; and failure to use models which reveal comprehensive sets of alternative management policies and their consequences. This paper will attempt to address these problems by sketching a comprehensive systems analysis which can be applied to estuaries, by indicating some of the implications of the systems approach, and by examining briefly some of the management policies and possible improvements in management techniques which are suggested by the analysis.

SOME SOURCES OF ENVIRONMENTAL DAMAGE TO ESTUARIES

The major threat facing our estuaries is cumulative and potentially irreversible environmental damage resulting from excessively rapid economic development and intervention in natural processes. Although numerous factors have contributed to this problem, a major set of components has emerged from economic forces.

The principal economic problem in the management of estuaries is the fact that they are generally treated as common property resources with no single ownership or management. Consequently, property rights are not vested and the result is that estuaries and their resources tend to be overused and abused since users do not normally bear the full costs of their use. Under these circumstances, market failures result since the private costs of using the resources of the estuary do not equal the social costs and the individual users attempt to appropriate as much of the resources as possible before they can be appropriated by others who also have free rights to them. With no single entity holding property rights or full management responsibilities, there are no incentives to invest in increasing or protecting the productivity of the estuary, and its resources tend to be overused and depleted.

Another problem which is related to the common property phenomenon in estuarine management is the imposition of detrimental externalities on others. The apparently free availability of water, air, and biological resources in estuaries makes it possible and profitable (at least in the short run) to overuse these resources and to shift costs from particular individuals, groups, and communities, to others. This phenomenon is most clearly observed in the release of wastes into the air and water of estuaries. Firms attempting to maximize profits, individuals attempting to maximize personal utility, and communities attempting to minimize costs and shift their environmental loads elsewhere, face positive incentives to discharge their wastes into estuaries, thus imposing damages, costs, and injuries upon other groups, other reaches of the estuary, and upon the biological resources of the estuary itself without paying compensation.

Other types of market failure also combine to encourage mismanagement of estuaries. For example, many of the recreational, aesthetic, and environmental values of estuaries can be regarded as public goods which are normally provided in the public sector. Although the benefits resulting from the provision of these public goods usually exceed their costs, up to a certain level, the public sector normally provides insufficient investment in the management and protection of estuarine services, for a number of reasons. Taxpayers may be reluctant to reveal their

Table 1.—Gross Residual Projection for Nitrogen for the Chesapeake Bay Region (tons)

	Years				Average Annual Growth Rate 1970–1985
	1970	1975	1980	1985	
District of Columbia					
Potomac	4,032.7	4,252.4	4,746.8	5,214.8	1.7
Maryland					
Blackwater	487.2	525.0	542.5	551.6	.8
Chester	4,696.4	5,526.3	6,336.1	6,876.6	2.6
Choptank	10,721.2	11,868.7	12,816.9	13,440.2	1.5
Gunpowder	4,462.4	5,029.4	5,400.6	5,560.9	1.5
Nanticoke	3,088.9	3,340.6	3,495.8	3,617.2	1.1
Patapsco	6,309.8	6,309.8	7,139.6	7,212.5	.9
Patuxent	12,641.5	13,802.7	14,078.7	14,421.6	.9
Pocomoke	6,802.5	7,291.6	7,521.9	7,772.2	.9
Potomac	47,979.5	50,891.9	52,343.6	52,482.8	.6
Wicomico	8,067.9	8,624.9	8,875.6	9,145.6	.8
Elk	3,898.1	4,460.8	5,069.7	5,575.7	2.4
Ches. Bay and ocean	30,092.2	32,602.6	34,425.1	35,634.6	1.1
Total	139,247.4	150,504.0	158,045.9	162,291.4	1.0
Virginia					
James	29,956.5	48,850.0	79,234.1	122,084.0	9.8
Potomac	15,088.8	23,024.4	35,782.5	53,028.2	8.7
Rappahannock	12,799.8	22,386.9	38,444.0	62,038.6	11.1
York	10,840.1	17,875.6	29,481.1	46,196.8	10.1
Ches. Bay and ocean	12,592.4	16,292.5	21,398.4	27,888.4	5.4
Total	81,277.6	128,429.4	204,340.0	311,235.8	9.4
Chesapeake Bay Region total	224,557.7	283,185.8	367,132.7	478,742.0	5.7

Source: Cumberland and Herzog, forthcoming.

preference for added expenditures in the public sector fearing that their taxes will be raised and hoping that other groups and other regions will pay for the improved management. The joint difficulty of either collecting fees for cleaner waters or of excluding anyone from enjoying the free benefits therefrom is a serious deterrent to public programs needed to protect estuarine quality. Also, organized pressure groups with well-defined financial objectives are usually more successful in influencing public expenditures in their direction than is the general public which benefits from the diffuse, long-term services of a well-managed estuary.

Another problem in the management of estuaries is the failure to utilize models which permit experimentation with a wide range of alternative development plans. Too often in the past, preoccupation with growth and quantitative increase of gross product has tended to distract attention from other alternatives such as non-development, low-density development, recreational development, and protection of common property resources for the future. Flexible models are needed which can trace the economic and environmental implications of all of these policy alternatives.

Two major sets of problems in estuarine management are caused by the inability of current economic management models to allow full consideration of interregional, interspatial, and intertemporal phenomena. With respect to intertemporal phenomena, decisionmaking for estuaries is typically based upon market rates of discount and profit considerations which attach low values to the rights of future generations. The result is often to encourage irreversible actions which may generate current benefits at the cost of foreclosing future alternatives. More adequate consideration of the values of future generations is required.

The failure to consider future generations and the use of high discount rates also tend to ignore important time changes in economic variables. For example, there appears to be growing evidence that with affluence, there is a high income elasticity of demand for outdoor recreation; yet, adequate protection of estuaries for recreational purposes has been systematically undervalued as compared to industrial and commercial development. A second and related phenomenon results from changing technology. For example, the rush to use the cooling capacity of estuaries for installing fossil fuel and nuclear electric steam power stations overlooks probable future technological developments which will make more use of solar, geothermal, and other forms of energy less damaging to the environment than present steam electric stations (Krutilla and Cicchetti, 1972). Another phenomenon connected with technology is the growing tendency towards introduction of high-technology, high-pollution devices in recreation. For example, the growing use of high-powered engines for water skiing, boating, helicopters, and other aircraft is converting many recreational activities into high-noise, high-pollution activities.

Other problems related to time in the theoretical analysis of estuarine management deal with the neglect in most resource management theories of the irreversible nature of some activities. For example, some types of estuarine abuse such as excessive sedimentation and filling in of the estuary, or massive oil spills, or the releases of radioactive isotopes with very long half-lives may have an effect on the estuary that is irreversible. Reversibility can be defined in terms of the amount of cost involved in correcting an adverse effect. Under this definition, certain types of management decisions may be irreversible, or they may be reversible only at extremely high costs. Among these would be the decision to construct a highly capital intensive activity such as an industrial plant, a power plant, an industrial port, or even a high density recreational or residential area. The phenomenon of irreversibility as it affects estuaries therefore requires that sequential life-cycle analysis be included in models of estuarine management under which the economic and environmental effects of the project should be evaluated over all phases of its life. This would include exploration, planning, construction, operation, and the eventual removal of the project and rehabilitation of the site.[3] The inclusion of intertemporal, sequential phenomena is urgently needed if models of environmental estuarine management are to be improved (Fisher, Krutilla, and Cicchetti, 1972; Fisher and Krutilla, 1974; Arrow and Fisher, 1974).

Besides including intertemporal phenomena, improved models should explicitly contain interregional, interspatial variables. A major tendency in regional waste management problems is to shift emissions of wastes to other regions, using common property resources such as air or water to transport waste burdens from one region to another. Much traditional analysis of urban problems fails to take into account the total environmental space of an urban region, which properly includes its entire watershed and its entire waste disposal space, covering perhaps hundreds or thousands of square miles. Consequently, estuarine models should explicitly contain the full environmental space of the region as well as an

[3] The closer the costs of removal and rehabilitation approach infinity, the more nearly the project would be truly irreversible.

explicit interspatial network of all of the separate governments involved.

Closely linked to the regional economic factor is the regional political management problem and the need for appropriate management units for estuaries which include the relevant physical and environmental units. Related to this is the fact that responsibility for estuarine environmental decisionmaking is often entrusted to transient personnel who may have at best a short-term or bureaucratic interest only, rather than a long-term commitment to the health and protection of the estuary. Another institutional management problem is the failure of environmental planning units to include representatives of all of the necessary disciplines involved. Too often these regulatory commissions have a commitment to economic development rather than environmental protection. Political factors obviously reinforce this issue.

The net result of all of these economic and related problems in estuarine management is usually to encourage excessively rapid development, overuse, and abuse of common property environmental resources so that private costs are lower than the social costs. The private gains resulting from damage to the public interest offer incentives to individual developers to overuse the resources of the estuary. The resource management problem then turns out to be in large part one of avoiding the major abuses of market failure through simulation of optimal decisionmaking which in theory results from single management and ownership of an environmental resource.[3] The estuarine management task then is to maximize public welfare and utility by balancing the gains of economic development against the claims of responsible environmental management in order to maximize total net social benefits to the society. It is the hypothesis of this paper that failures to do this in the past have resulted from 1) inadequate theoretical understanding of estuaries; 2) failure to include interdisciplinary knowledge that is emerging from ecological analysis of estuaries; 3) failure to base estuarine management models on knowledge of environmental economics; 4) failure to design models which show all of the full range management options; 5) failure to include long-run phenomena; 6) and failure to design adequate institutions which can implement the knowledge resulting from better management models.

In the next section, an effort will be made to sketch some of the details of a comprehensive estuarine environmental systems management model.

[3] Optimal decisionmaking also requires the free availability of knowledge, low transactions costs, and other conditions usually associated with pure competition.

APPLICATION OF SYSTEMS ANALYSIS TO ESTUARIES

Estuaries are complex systems of natural phenomena, of human activities and of the interrelationships between society and nature. The realities of these large systems are too complex to be represented by simple models. However, as in the case of any management problem, an effort can be made to identify the most critical subcomponents of the estuarine system and the interrelationships between them. Figure 1 represents an effort to model the major components of an estuarine system and its interrelationships.[4] It contains eight components which, being separate and distinct, can be solved individually, but which can also be linked together with measurable interrelationships in a way which provides feedback from one system to another, generating a closed general equilibrium system. Part A is a regional, or more generally an interregional interindustry or input-output model which has been widely used by economists (Cumberland, 1966). There are several important characteristics of these interindustry models. One distinctive feature is the emphasis on disaggregation of economic systems by type of economic activities. For example, Figure 1 specifically identifies energy sales across the energy row and energy purchases down the energy column, because of the importance of energy policy problems at the present time and because of their significance for estuarine management. However, because energy activities purchase inputs from many different activities as shown in the energy column and because energy producers sell outputs to almost all other economic activities, as demonstrated across the energy row, it is impossible to measure and evaluate energy activities in isolation from the rest of the economy. Therefore, separate analysis of energy isolated from the rest of the economy can lead to erroneous, misleading, and inefficient decision processes. Energy factors should be incorporated explicitly in a general equilibrium model of the region.

A second major advantage of the interindustry module is that separate identification of each economic activity in the model permits the comprehensive measurement of indirect, as well as direct, effects of each of the economic activities. This is important because indirect effects if comprehensively accounted for can add up to significant magnitudes. Another advantage of the disaggregation of the interindustry

[4] Although the economic environmental systems model displayed in Figure 1 is used for application in this study to estuaries, it has been developed by the author and his colleagues for general application to economic environmental management problems of regions, urban areas, and other systems. See for example (Cumberland and Stram, 1974; Cumberland and Korbach, 1973).

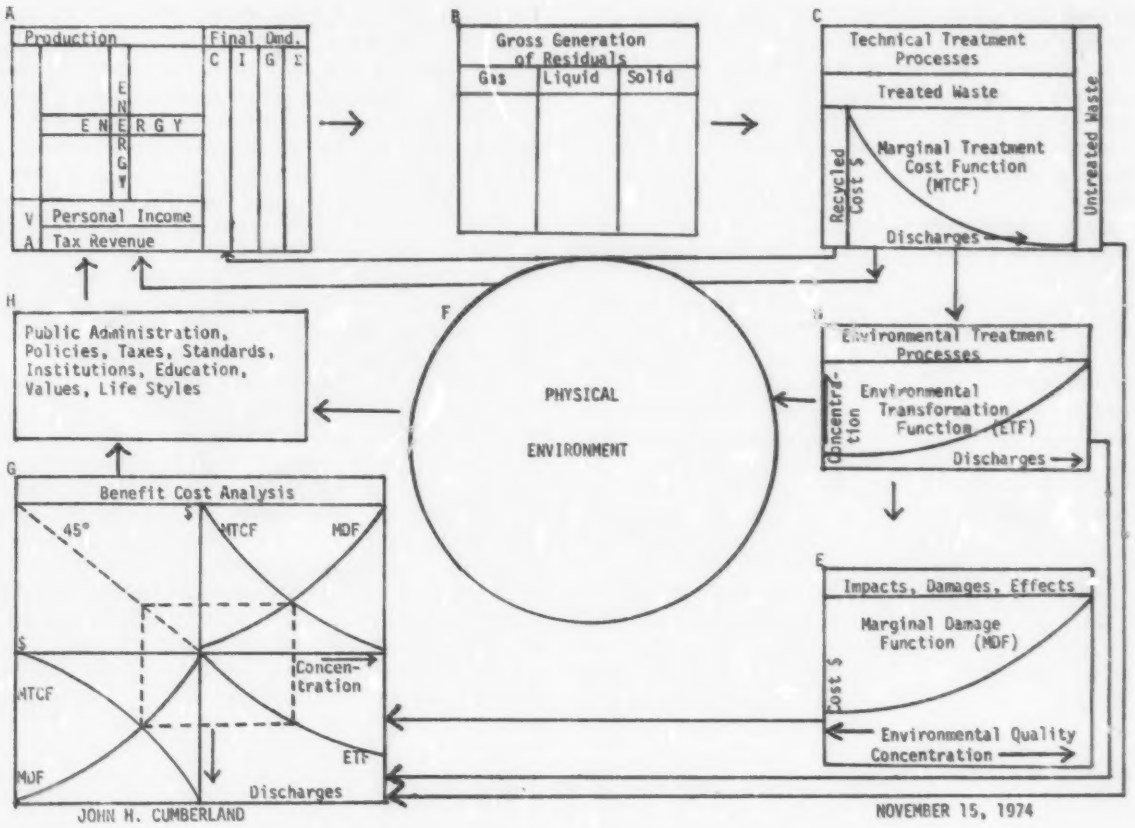

FIGURE 1.—An economic environmental systems model.

model by economic activity according to function is that it records the important distinction between the final demand sectors and intermediate processing sectors. This distinction permits recognition of the fact that economic growth is not mechanical or inevitable, but is a function of the goals and priorities of the region. The decisionmaking sectors are separately identified as consumers or investors or government for whose total final demand satisfaction the intermediate processing sectors are activated. This formulation has the important additional advantage of making it possible to enter alternative growth strategies or policy programs into the model (so long as they can be specified in terms of purchases from the sectors in the model) in order to measure the impact of these alternatives on income, employment, output, and environmental quality. In an alternative linear programming formulation, the model can also be used for indicating, given the goals and objectives of the estuarine region and its environmental structure, the optimal set of economic policies and activities needed to achieve these regional objectives. Trade-offs between environmental quality and economic objectives such as income, employment, and tax revenue can also be measured.

While economists have achieved considerable proficiency in developing the economic models of the type shown in Part A, they have learned recently from the growing magnitude of environmental problems that economic models have omitted some of the most important interrelationships from their market-oriented models. Since interindustry models normally measure only those goods priced and exchanged in markets, they have omitted the flows of wastes and residuals which are a counterpart of all production and consumption activities. Although the materials and energy balance concepts have been dealt with by physicists for many years, they have only recently been introduced into the analysis of economists (Ayres and Kneese, 1969; Georgescu-Roegen, 1971). Profit-maximizing firms have ec-

onomic incentives for discharging their wastes at low or zero costs into the common property resources of the estuary, causing overuse of the limited assimilative capacity of estuaries and reductions in total welfare. The abuse of the common property estuarine resources is not limited to profit-maximizing firms, but is also a factor in the economic incentives of consumers and recreationists to discharge their wastes into estuarine waters, and to overuse the common property amenities provided by estuaries.

Thus, difficulties associated with allocating and enforcing property rights to estuarine resources, and the historical common property status of the estuary which provides positive financial incentives to both producers and consumers to overuse these resources and discharge wastes into them, account largely for the environmental problem and the growing pollution of estuaries. An attempt is now being made to measure the flow of these wastes and residuals through the environment in new types of development models which measure and forecast both the types and the amounts of wastes that accompany each type of production and consumption activity (Cumberland and Korbach, 1973). This type of model measures the flow of wastes and residuals coming from each type of economic activity in the Gross Residuals Component B of Figure 1. The model is disaggregated not only with respect to every production and consumption activity, but with respect to each major type of pollutant discharged into water, air, and onto the land. The importance of disaggregating waste by type, source and destination can be suggested by considering the different environmental qualities and characteristics of different estuaries. Estuaries having cold water and great depths, such as Puget Sound, may be less damaged by some types of residuals (i.e., thermal) than would other estuaries, such as the Chesapeake Bay, which is characterized by shallow depth and warm waters. This type of model measuring the gross generation of residuals is a logical extension of economic interindustry models and now is being implemented by numerous research groups.

The growing importance and necessity of treating wastes and residuals makes it important to develop models of the alternative procedures and the costs involved in treating wastes and making them less harmful. This type of information is included in The Technical Waste Treatment Component, C, of the systems model, which includes the many technological options for treating each type of waste in each location. A critical point to be noted about technological treatment of wastes is that while residuals can be treated in many ways—through dilution, transportation, recycling, changing the timing and place of the emissions, improving efficiency, choosing cleaner inputs, and so on—these treatment processes cannot eliminate or reduce residuals once they have been generated, because of the principles of conservation of mass and energy. Most treatment processes can only change the form or timing or location of the wastes discharged, and indeed add to the total mass of wastes released because of the necessity of adding energy and materials to the treatment process. The general exceptions to this principle are processes which use cleaner inputs, and processes which through technological efficiency use less materials and energy for the production process.

The other important factor to be noted about Component C dealing with technical waste treatment processes is the nature of marginal treatment cost functions which should be conceived of as being derived for each type of residual at each location over time. In general, these treatment cost functions rise asymptotically from the lower right-hand part of the diagram to the upper left-hand part of the diagram as increasing levels of treatment are invoked in order to achieve higher levels of treatment. The general shape and location of this curve suggests that large amounts of waste can be treated inexpensively[4], but that as higher levels of treatment are attempted, efforts to extract the last few percentage points of the residual and to achieve further increments of environmental quality, raise the costs of treatment per unit sharply.

The materials balance concept behind Component C for Technical Waste Treatment Processes is based upon the principal that wastes and residuals once created, cannot entirely be eliminated, and that the amount of residuals generated is a function of the level of economic activity, even if treatment processes are widely employed. Society is already encountering the problem of wastes which come out of waste treatment processes. Problems of dealing with the sludge from advanced waste treatment processes, and problems of the potential emissions from automobile pollution control devices are examples. The growing evidence of heavy metals and viruses to be found in residuals from sewage treatment processes provides another potentially significant example of this problem. Thus, the problem of contamination of the output of waste treatment processes by wastes from other processes may impair the capability of society for recycling wastes back into the economic system.

As shown in the Environmental Treatment Process

[4] For some treatment processes, economies of scale may cause high initial treatment costs, which then decline before ultimately rising. More empirical investigation of this problem is required (Grigalunas, 1972).

Component, D, of Figure 1, one of the major reasons for mismanagement and overuse of estuaries is the limit to the absorptive capacity and waste treatment capability provided by natural systems in estuaries. This phenomenon accounts in part for the powerfully attractive force which estuaries exert upon the location of industrial development, urban growth, power plants, and industrial harbor complexes. Water and other environmental resources of estuaries can receive, transport, transform, and treat large amounts of wastes which are discharged from natural processes and indeed from other waste treatment processes. However, as shown in Component D, as discharges become large with respect to the absorptive capacity of the environment, waste concentrations begin to build up and quality of the environment is changed. The increasing concentration of wastes in the water, air, and other environmental resources results in lowering the ambient environmental quality of the estuary. The relationship between discharges, concentration, and ambient environmental quality can be shown by an environmental transformation function (ETF) as demonstrated in Component D of Figure 1. The next important analytic step is to translate changes in environmental quality into some estimate of the quantitative impact of reduced environmental quality on human beings and other species which depend upon or utilize estuarine resources. This analysis is shown in Component E.

Component E attempts to relate the concentration of pollutants or the ambient environmental quality shown in Part D into costs to and effects upon the species dependent upon the estuary. An example is the effect of the reductions in dissolved oxygen upon the survival of the species in the estuary. Another example is the impact of increased water temperature during the spawning season on the survival of various species in the estuary. Relationships of this kind are measured in Part E of Figure 1, as damage functions.

If all the information as discussed up to this point is available, then this information can be utilized in a benefit-cost analysis which generates management-relevant information indicating how management of estuaries can be improved in the general public interest. In Component G of the model, information from all of the other modules is combined in order to derive standards for socially efficient (cost-minimizing) management of the estuary.[6] This diagram also suggests other management strategies. The purpose of combining all of this information is to provide management authorities with information on how to anticipate the amount of discharges and how the amount of discharges will affect pollutant concentration and environmental quality. This information on ambient environmental quality and concentration can then be translated into marginal damage functions and marginal treatment cost functions which indicate in the upper right-hand quadrant of Part G, the optimal level of concentration, or, from the lower left-hand quadrant, the optimal amount of discharge into the estuary. On the other hand, it may be possible to use even limited information about the benefits and costs to improve management efficiency (Fisher, Krutilla, and Chicchetti, op. cit.) Alternatively, these optimal amounts of discharges or concentrations can be translated in the upper left-hand component into an optimal emissions charge, or pollution penalty which would have the effect of providing emitters with financial incentives to limit their discharges to an optimal level. As shown in Part G, for any emitter emitting more than an optimal amount of emissions into the estuary, this policy would require his paying an emissions charge that was higher than the cost that he would incur by treating the waste. Conversely, the emitter would not be required to cut back his emissions below the optimal point because the cost of treatment would be greater to society than the amount of damages that would be prevented.[7]

In summary, benefit-cost analysis lies at the heart of the environmental systems model since it pulls together all of the relevant information in order to provide managers with (1) specific information on setting of standards for environmental quality; and (2) information on potential policy instruments for achieving optimal environmental quality. Since the logic of benefit-cost analysis simply asserts that efforts to improve environmental quality should be pursued up to the point at which benefits equal costs, it should be acceptable to both environmentalists and economic developers. These two groups, however, typically disagree strongly on the scope and position of the benefit and cost functions, thus differing upon the optimal level of environmental quality and upon appropriate levels for emission charges.

Even if all the vast amount of information and analysis required for the benefit-cost analysis and for

[6] For additional detail on Component G, see Freeman, Haveman, and Kneese, 1973, who use a similar formulation.

[7] An important technical point to be emphasized is that the optimal amount of discharge and hence the optimal emissions charge will vary between estuaries and indeed, over different tributaries and reaches of the estuary, depending upon varying assimilative capacity as measured by the transformation function in Component A. Therefore, full inter-spatial and inter-temporal implementation of the model would require time series forecasting of each type of economic activity and its associated residuals for each location (Cumberland and Herzog, forthcoming).

the rest of the economic environmental systems model were available and known, there is no assurance that this information and analysis would be used to improve management of the estuary unless certain other institutions and conditions existed. It is first of all essential that appropriate information and educational channels are available for transmitting and clearly communicating the information from the model to the general public and to the decisionmakers. Secondly, there must be institutions capable of utilizing the scientific management information. It is also necessary that people understand the effects of their personal lifestyles and values as expressed by their consumption patterns, on the quality and future status of the estuary. It is also essential that management institutions have available not only the legal authority, but also adequate financing and the range of management procedures needed to implement management aims.

Any total systems management model must therefore reflect the important role that the public, institutions, and management agencies play in decisions on investment, consumption, government programs, laws, and policies. As indicated in Component H of Figure 1, these private and public management institutions then feed back changes in information and priorities into the economic sectors of the model which again affect changes in output, altering its composition and size, and therefore, the generation of wastes and residuals.[8] Thus the cycle is completed and the model is closed in a total general equilibrium system.

RECOMMENDATIONS FOR IMPROVED MANAGEMENT OF ESTUARIES

The interrelationships between the various components of the economic environmental estuary system proposed here suggest a number of directions in which improved environmental management may be pursued. Some obvious points are that the management institution and its geography should be coterminous with the total environmental space of the estuary, embracing all of its tributaries and inputs, as well as its areas of discharge, the total atmospheric environment, and all of the land mass from which waste and discharges are emitted into the estuary. This is a very large order which must be interpreted reasonably, but in general, effective estuarine management will depend upon close control over the environmental emissions into the total system, and successful estuarine management will depend upon the creation of the management institutions appropriate to the task.

The second major conclusion concerning improved estuarine management is that the principal management priority is to offset the market failures which result from the common property aspects of the estuary by establishing an appropriate set of controls which bring the private costs of using the estuary's resources into line with the social costs, thus preventing the abuse and overstress of the estuary.

The third major implication of the model is that a large amount of data, research, and analysis will be necessary to achieve these objectives. However, if appropriate environmental quality standards can be established, there are fortunately a number of different management policies and techniques alone or in combination, which can be used to achieve them. One of the most important sets of management techniques is simply the establishment of environmental standards by law, by zoning, or by other regulations and ordinances. Another potentially very attractive set of management policies is the use of emissions charges. It can be demonstrated in Part G of the model that establishing an appropriate level of emissions charge is a potentially efficient device for limiting the discharge of residuals into the estuary to the level representing an effective social balance between the demands of economic development and environmental responsibility.

One of the most important potential attractions of using an emissions charge is that the proceeds from such a charge could be used to achieve some other objectives of environmental management. Often it will be necessary to establish new commissions for estuarine management, particularly when the problem is interstate, inter-county, or interregional. Management institutions need to be financed, and to have an adequate research and information base. The proceeds of a properly designed set of emissions charges in an estuary could be used to finance a management commission and to support the research needed, particularly the interdisciplinary research required to determine transformation functions, damage functions, and optimal environmental standards. These funds could also be used for monitoring the release of emissions and enforcing the standards (Cumberland, 1972). Some possible regulations and policies that an estuarine management commission might apply to improve management and to increase public welfare will be examined below. However, there are some potential dangers which should be considered in the use of emissions charges to support an estuarine management commission.

One is the hazard of becoming financially dependent upon these funds, and thus developing a vested

[8] The major conclusion of this paper is that the appropriate institutional component for estuarine management is an interregional commission partially supported by emissions charges.

interest in perpetuating pollution. Another problem pointed out by public finance theorists is that to the extent that the charges were successful in reducing pollution, they would earn very little revenue, and to the extent that they were successful in generating revenue, their effectiveness in pollution abatement could be debated. The example of accumulation of economic and political power associated with the Highway Trust Fund provides a warning against the potential abuses of automatically setting aside revenues for a specific purpose. However, it must be recognized that economic factors associated with the public goods problem systematically encourage underinvestment in environmental protection, unless special programs are developed. These problems suggest that emission charges might be combined with other environmental control measures as an important but not sole instrument for pollution control.

We have seen that the major task of managing estuaries is to achieve an appropriate balance between economic growth and development and the environmental quality of the estuary. Because of the common property nature of the estuary and the economic incentives of industry to discharge its waste at lowest costs, the primary management task for estuarine management will be to reduce the amount of residuals and externalities imposed upon one set of users by others, and to take a long-run view of the estuary as an ecological unit which must serve the needs of future generations, as well as those of the present.

The achievement of these objectives will call for judicious use of a wide range of management policies and techniques. These could probably best be achieved by management commissions set up as described and given responsibility over the total environmental space of the estuary with appropriate powers of planning, establishing standards, taxing, monitoring, and enforcement. There are many policies and sets of procedures that such an institution might use. Among the most promising would be a comprehensive set of emissions charges on all types of emissions and externalities. These charges, of course, should be related to both the assimilative capacity of the estuary and the damages that would be created by the discharges. It is important to note that these emissions and discharges are not limited to liquid, solid, and gas alone, but that they also include releases of energy in the form of heat, noise, and radioactivity. Some of the most urgent needs for effective improved management of estuaries are sharp reductions in the amount of thermal waste, radionuclides, and noise emission. Stiff charges could be applied to all of these pollutants. The benefits from applying charges to them all would be both to reduce the emissions and to provide financial incentives to the emitter to find improved technologies for reducing future emissions, thus sharing between both polluters and the society the benefits of reduced pollution. Establishing the principal of full responsibility of the emitter to pay for any accidental or other damage created by his activities such as oil spills, chemical spills, explosions, sedimentation damage to water tables, damage to aquifers, and so on, provides a strong incentive to prevention of damage (Cumberland and Fisher, 1974).

However, in addition to emissions charges and penalties, estuarine managers will also need other instruments such as the powers of planning and zoning to protect the wetlands upon which the health of the estuaries depends and to manage inland development which ultimately determines the amount of waste that is discharged into the estuary. In fact, the power of zoning should be extended from land to water resources. For example, increasing numbers of recreationists appear to be adopting high-technology, noise-intensive types of recreation such as water skiing and the use of high-speed water craft, dune buggies, trail bikes, aircraft and helicopters. Because they impose very great dangers, damages, disamenities, and discomfort on other users of the estuary, these activities should be heavily taxed, limited to restricted areas, and permitted in other areas only as contributors to public welfare (emergency vehicles). An appropriate balance between these competing demands can be achieved not only by establishing charges upon speed, noise, and horsepower, but also by zoning certain limited portions of the estuary for industrial, commercial, high-noise, high-speed activities, provided appropriate emissions charges were paid and by excluding these activities altogether from other parts of the estuary, regardless of emissions charges. In effect, the charges could be varied by zone, with an infinite charge for the use of some zones.

One of the most important sources of environmental externalities and estuarine damages is the military sector, and one of the most important opportunities for improving welfare through alternative uses of estuaries is to return some of the vast military holdings of tidewater areas to civilian use. The contribution of military security to society is widely recognized as is the need for certain amounts of secrecy and security in this area, but it should be equally recognized that the environmental costs of military activities are often excessive and unnecessary. For example, currently, military activities have the power to override the planning and zoning authority of local governments, as well as potential

estuarine management commissions. The magnitude and intensity of military activities result in their being a major source of congestion, accidents, noise, explosions, thermal release, radiation, and sonic booms, from the operation both of very large types of conventional vehicles and advanced weapon systems. Judging by the dollar value alone of military activity, and not allowing for any increased environmental intensity of military operations and experimental weapons systems, it is unquestionably one of the major generators of environmental externalities in estuarine regions.[9]

In view of the difficulty of local governments and management commissions in regulating military activities, a national policy is necessary in order to minimize their environmental impact and to achieve national efficiencies in geographically locating them in those regions where environmental impact can be minimal. In the long-run it would be desirable to return to civilian use all military properties located in estuaries where civilian activities are widespread. A national policy of returning estuarine based military activities to civilian use and removing military operations to unsettled regions could improve total national welfare through increasing the supply of public goods for recreation. However, an essential element of such a policy should be to offset local economic adjustment problems through compensatory policies, and through careful regulation of the public use of released military bases to exclude pollution-intensive forms of recreation. For example, very little justification in economic theory can be found for providing military recreation centers which favor privileged classes of individuals such as military people to the exclusion of the general public.

Subsidies and program assistance can also encourage creation of public goods which are not sufficiently generated by market processes. Among the activities which are particularly in need of subsidy are recreation, especially for wilderness areas, hiking and biking paths, ecological research areas, protection of critical marshlands, and prevention of shore erosion. Other types of activities for which subsidies might be provided are actual removal of offensive activities, such as pollution-intensive power plants and military bases, as discussed above. Another type of public good worthy of subsidies is historic restoration, such as Williamsburg in the tidewater area of Virginia and St. Mary's City in the tidewater area of Maryland. Subsidies should also be considered for those types of activities which are environmentally beneficial or neutral, such as windmills and solar energy devices.

[9] In the Chesapeake Bay region, military activities dominate major segments of prime air, land, and water resources, creating extensive planned, and often accidental explosions under water, on land, and in the air.

SUMMARY AND CONCLUSIONS

This paper has also emphasized improvement in estuarine management through the creation of estuarine management commissions which are geographically coextensive with the estuary and its total environmental space. This problem is not only economic, but also political in nature and the composition of such management commissions is critical. Once again, recognizing that bias in estuarine management tends to be heavily in favor of excessively rapid economic development and short-run revenue producing activities, the usual economic and political representation of such commissions should also be balanced with participation of citizens' and conservation groups whose long-run views merit at least a hearing. Providing clear channels for citizen participation in environmental management is an essential corrective to the usual problem of concentrated economic and political power used to distribute heavy pollution burdens widely over large populations which then face heavy costs in organizing to protect their welfare.

The national policy on estuarine management should recognize the principle that the federal government establish minimum environmental standards, but that local areas, including estuarine management commissions be permitted to veto local developments and to establish higher environmental quality standards than the federal minimum. The justification for this point of view is not only recognizing local preferences and seeking improvements through permitting local choice, but also encouraging improved technology by establishing very high performance standards at the local level so that would-be polluters have positive incentives to seek cleaner technologies. Such local citizen activity has already resulted in the refinement of nuclear technology and other energy systems. Since market processes usually combine with economic and political power to generate excessively rapid development and intensive overuse of estuarine resources, recent proposals to permit the federal government to override local preferences for non-development, or to require states to set aside energy development areas regardless of local wishes seem inefficient economically, and politically indefensible in a federal system.

A most important part of life cycle planning is recognition of the fact that all residuals should be specified which would be generated by any proposed development through every phase, including exploration, construction, operation, and eventually rehabilitation of the site. Complete life cycle planning based on materials balance concepts would require that the producer specify exactly what inputs would

enter into the process, and exactly what ultimate disposition would be made of all of these inputs. Component C of the systems analysis should warn that even treatment is not enough, for treatment processes involve wastes whose ultimate disposition has to be specified and paid for, preferably by the emitter.

Another reason for restraining market-oriented irreversible development is the need for keeping open options for the future. As Krutilla and Cicchetti have emphasized, changing technology plus changing income elasticity of demand for recreation will probably increase the future value of unspoiled recreational resources and reduce the present value of technology-intensive activities (Krutilla and Cicchetti, 1972).

Aesthetic damage to shorelines, skylines, and other estuarine resources is a costly type of environmental pollution. Although the cost may be spread out over a large number of people over a very long period, realistic measurement would indicate a serious decrease in social welfare. For this reason, all of the policy measures discussed above such as charges, controls, and subsidies should be used to discourage large physical intrusions of any kind and to subsidize protection of natural landscapes. Examples of visual pollution are bridges and power lines which appear to diminish the magnitude and majesty of a body of water or a distant skyline. Where such facilities are regarded as essential, the alternative of using tunnels rather than bridges and of undergrounding powerlines and pipelines rather than permitting them aboveground should be encouraged by economic and other incentives.

Finally, an important feature of estuarine management commissions would be their research capability. These institutions could advance the art of environmental management through continual research on damage functions as indicated in the systems model and by giving the regional commissions the capability of forming independent estimates of the impact from proposed activities. One promising format for the research arm of such estuarine management commissions is the Chesapeake Research Consortium in the Chesapeake Bay region (1971–1972). Another opportunity to finance and encourage environmental research and public goods activities is through the sea grant program, under which local institutions can be encouraged to develop the multidisciplinary research capabilities called for in Figure 1 for estuarine management, research, and policy formation.

Because of the vulnerability of our estuaries, developing the knowledge, skills, and institutions needed to reverse the damage now being done to them will not be an easy task. However, the lesson to be learned in improving our management of these vital resources will be a crucial step in mankind's belated efforts to recognize his responsibilities for long-run protection of his total environment on earth. The systems analysis presented in this paper suggests that establishment of interregional, interdisciplinary management commissions, financed partially through emissions charges, and with broad powers to levy these charges, conduct research, monitor environmental quality, and control land and water use is a promising institutional approach to the protection and management of estuaries.

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ESTABLISHING THE ECONOMIC VALUE OF ESTUARIES TO U.S. COMMERCIAL FISHERIES

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ABSTRACT

The economic importance of estuaries is assessed in their supportive role of the U.S. commercial fishing industry. Economic welfare concepts are related to major phases of the fishing industry, and empirical estimates of these values are surveyed in the literature. The exvessel price of landed species is cited to be a conservative estimate of net benefits realized by all phases. The literature survey reveals that most economic studies of fishery benefits are conducted without any apparent knowledge of valid welfare concepts. This gap between empirical and theoretical constructs must be eliminated if economic values are to be plausible and meaningful.

INTRODUCTION

The estuaries of the United States have traditionally nurtured a significant portion of the total commercial fish catch. Records dating back to the early colonization of America reveal a close link between economic development and estuarine resources. For New England pilgrims facing cold winters, clams and mussels were the major diet during the periods of food storage. Some communities along the Atlantic coast depended almost entirely on the fishing industry and related activities, such as shipbuilding and the construction of marinas. Identified as the most naturally fertile environment in the world (Odum, 1961), estuaries provide a haven for fish and shellfish at various stages of their life cycle. It is estimated (Stroud, 1971) that, depending upon the geographic region, 65 to 90 percent of domestic fish landings are comprised of estuarine-dependent species. Furthermore, there is the enormous potential of increasing usable catches from estuaries by mariculture, improvement of fishing efficiency, and increased harvest of underutilized species.

Despite the recognized importance of estuaries to the economy and welfare of society, these areas are often exploited for dredging and landfill operations that permanently imperil fishery resources. These damaging activities are usually justified in monetary terms for industrial, residential, or commercial development purposes.

The conservation of fish habitat, on the other hand, is more difficult to evaluate in economic values. Yet without such an evaluation, competing water uses will continue to be the primary factors considered in estuarine development cost/benefit analyses. It is therefore to the net benefit of society that guidelines be established to achieve a full consideration of the values of fisheries. Without the development and wide application of such guidelines to coastal zone decisionmaking, the Nation will continue to lose segments of its estuaries to residential and industrial development, with corresponding declines in fisheries stocks (Roberts, 1974).

This paper surveys methods to quantify the economic benefits of commercial fishing and then relates them to empirical studies of specific estuaries. The following section reviews current statistics of U.S. commercial landings and the relative importance of estuaries. The next section outlines the theoretical basis of welfare economics, and then applies these concepts to benefit estimation at the fish catching, processing, and marketing phases. Distinctions are recognized between direct benefits of the fishing industry and indirect benefits to the regional economy.

Following this is a summary of published values of estuaries throughout the nation and an economic assessment of fishery losses from marine pollution. In the next section the various problems of benefit assessment are discussed as they affect the accuracy or credibility of empirical values. To conclude the paper, specific recommendations are made for a comprehensive benefit evaluation of estuarine-dependent fisheries and for management policies that fully recognize these values in coastal zoning decisions.

ESTUARINE-DEPENDENCE OF FISHERIES

In 1973 the total value of reported commercial fish landings in the United States was more than $900 million (National Marine Fisheries Service, 1974). At least two-thirds of that amount is derived from estuarine-dependent species (McHugh, 1966).[1] While much essential biological information remains to be acquired on habitat dependencies, there is a general consensus among fisheries experts (Stroud, 1971) that the following commercially important species spend at least part of their life in the estuarine zone: black sea bass, bluefish, clams, (all soft clams and some hard clam species), crabs (except king and tanner crab), croaker, black drum, red drum, American eel, flounder, lobster, menhaden, mullet, oysters, porgie, puffer, salmon (chinook, coho), seatrout, shrimp, spot, steelhead, striped bass, sturgeon, tarpon, tautog, and weakfish.

Published statistics on the exvessel value of particular species give strong testimony on the significance of estuaries to the commercial fishing industry and the American economy as a whole (National Marine Fisheries Services, 1974). Of the 10 most valuable species landed in 1973, eight are directly dependent on the estuary and represent over $660 million in dockside revenue. This figure does not include the value added (i.e., revenue less raw material costs) from the processing, wholesale, and retail sectors.

While the literature on most commercially important estuarine-dependent species has identified the unique life-supporting role of estuaries, there is little quantitative information on total standing crops of particular species (Clark, 1974). As a result, fisheries scientists are unable to predict with confidence just how much estuarine acreage is necessary to maintain existing fisheries at any level of catch effort. This situation greatly complicates cost accounting of commercial fishery stocks which are threatened by estuarine degradation.

Mariculture

The farming of marine animals in the U.S. estuarine zone is not as yet practiced to any appreciable extent (other than perhaps the Atlantic coast oyster industry). After more than a decade of intensive public and private research on this topic, there still are major economic, legal, and technological barriers in this country to establishing a viable aquaculture industry (Gates, 1971). (In certain Asian and European countries, on the other hand, the rearing of finfish and certain types of shellfish is well established.) Efforts to raise salmon in estuaries of the Pacific Northwest are hampered by high costs, while research attempts to raise shrimp along the gulf coast are in the preliminary stage but do look promising for the future. Should these efforts meet with success, however marginal, they will add yet another dimension to the value of the estuary. In cases where conflicts arise between mariculturists and natural fish harvesters, detailed management strategies will be needed to accommodate both interests at some socially optimum combination.

[1] While a two-thirds ratio is the most commonly quoted figure, several estimates range as high as 75–90 percent, with the upper figure cited for catches along the gulf coast (Newsletter, 1974; Atlantic States Marine Fisheries Commission, 1966; Stroud, 1971).

THE CONCEPTUAL FRAMEWORK

The economic benefit of a resource is the gain in real income or consumer satisfaction realized by the use or consumption of that resource. However, many benefit estimates are made without a valid economic rationale. The assumptions and techniques used in estimating benefits need to be checked against sound, economic theory to determine their validity.

The concept of benefits, as proposed in this study, conforms to basic ideas of welfare economics. By definition, the gross benefit of estuaries in terms of commercial fish is the maximum amount that society would pay for the actual or potential yield of fish. In a socially optimum allocation of resources, this amount will at least equal the value of all goods that society has foregone in order to obtain the output from the fishing sector. According to economic terminology, this foregone value is called the opportunity cost of fishing and should be subtracted from gross benefits to estimate the net benefits. Net benefit is the willingness-to-pay value after total production costs are subtracted.

The fishing industry is comprised of vertically integrated phases that include the catching of fish, the processing and distribution of fishery products, and retail marketing to the final consumers (Bureau of Governmental Research and Service, 1969). Each of these activities contributes to the net benefits of commercial fishing. The net benefit of each sector, i.e., the value of the output of the sector after subtracting total production costs, is also known as the value added by that sector. The following remarks pertain to the most valid guidelines of assessing the net benefits at each phase.

The Catch Phase

Fishermen constitute the most fundamental link in the chain. Most benefit estimates in the literature

narrowly focus on fishing revenues. It is commonly assumed that net benefits are calculated as the difference between dockside catch value and fishing costs of capital, labor, and other input factors. Unlimited entry into the fishery grounds entices too much capital and labor input in the industry. As a result, net benefit calculations, the difference between value of catch and fishing costs, are often zero or negative in the long run. The invalid implication of this logic is that commercial estuarine fishing does not enhance social welfare.

An alternate approach has been suggested (Crutchfield, 1962) to overcome this dilemma. The rent or value of the resource should be calculated under the ideal situation wherein only the most efficient fishermen have access to fishing grounds. Net benefit is then determined at the economic optimum level of output given the least cost strategy of production. This implies a reduction in the size of the fishing fleet and manpower requirements, which in turn would allow the "excess investment" to be utilized in more beneficial sectors of the economy.

While this approach can provide a reasonable empirical value, it neglects certain welfare impacts by not quantifying all of the benefits and should be modified accordingly. For example, the excess investments due to free entry may be indicative of society's preference for a larger fishing fleet and its protection of one of America's oldest labor markets. Any attempt to dislodge these excess investments could induce drastic changes in the prosperity of fishing ports, the displacement of fishermen and their families, and a reduction of scenic amenities provided by picturesque fleets and colorful old fishermen tending to their daily chores.

On the other hand, it could be contended that excess investments in fishing are not preferred; rather they are forced upon society as a result of an historical misallocation of resources. This resource immobility accounts for a portion of the potential rent, and, if at all possible, should be deducted in the estimate of net benefits.

Some resource analysts (Gosselink, 1973; Hite, 1973) claim that the entire landing value of fish should be imputed to the net rent of estuarine areas, as an indication of "the dependency of jobs and commercial fisheries on the existence of these free resources." This assumes that capital and labor commitments to the fishery cannot be shifted to other uses. In the short run, this assumption seems valid for some fisheries where the commercial fishermen are quite old and entrenched in their jobs despite relatively low incomes, and where the conversion of boats and fishery equipment into other uses is technologically impractical. Yet over the long run, these resources will eventually flow into more profitable uses. As old vessels are retired, the materials and labor necessary to replace them will be used in other industries. Fishermen are less likely to find new employment, although this is not a universally accepted opinion.[3]

In a meeting (McQuigg, 1971) of Canadian scientists, it was concluded that landing price may significantly underestimate net benefits aggregated over all phases of the fishing sector. Direct benefits include current net rent to fishing, processing, and marketing profits. Indirect benefits include the additional income and employment generated, if any, in coastal communities in other industry and service sectors as a result of the commercial industry and fishing. Another analysis (Bell, 1974), of international fishery values, claims that the exvessel price is an adequate proxy for net benefits to the consumer. Unlike the Canadians' emphasis on producer benefits, this conclusion pertains exclusively to welfare impacts from the retail market as discussed later.

The Processing and Distribution Phase

Intermediate activities of the fishing sector begin with the wholesalers who purchase the catch at dockside and then extend to include processor, distributors, and the retail markets. Net benefits attributable to this phase are usually ignored in the literature because of the lack of readily accessible data. To date, few estimates of such values have been attempted. It assumes that the total value added by processing and wholesaling sectors reflects net welfare (Carley, 1968). Whether value added represents a good approximation to net benefits remains to be proven. According to economic theory, monetary benefits are determined by the excess profits or producer surplus earned by this phase of the industry. The magnitude of this benefit depends upon the profit-making potential of the industry.

The number of processor-wholesaler firms has declined in recent years and those remaining have broadened their sphere of influence and increased their profit-making potential by handling more fishery products and adding restaurants or retailing facilities to their investments. Profit-making potential is also obtained by controlling a large enough share of the market to influence prices. Interferences

[3] For example, a recent study (Strang, 1974) on charter boat fishing in the Great Lakes found the age distribution of fishermen to be bimodal, with a significant portion over 50 years old and another concentration in their twenties. The latter group is particularly mobile, and could thus find employment elsewhere, in view of current opportunities in this country for non-professionals in skilled and unskilled jobs.

with the price mechanism have been cited (Hite, 1973) for the tuna canning sector, where unit landing prices are set prior to the catch by a cooperative of vessel owners and fishermen. Such activities could introduce excess profits, which nevertheless, should be included as a component of net benefits.

Retail Sales Phase

The value of fishery resources depends on two sets of complex market forces. The above discussion broadly recognizes the supply side including the cost of harvesting, processing, and distribution of fish products. There is also the demand side which takes into account the consumers' preference for fish and shellfish. The intensity of this preference is reflected in the prices that individuals are willing to pay for various commodities, given current or foreseen consumption alternatives in the market. Conceptually, net benefit to consumers is the difference between what they pay for fish and fish products and its value to them. This concept is referred to as consumers' surplus.

The demand for any fishery product depends upon individual tastes, level of income, and prices of that product as well as the price of related goods. The U.S. per capita consumption of fish and shellfish has remained virtually constant in this century indicating that tastes have remained relatively constant. In the past, the quantity of fishery products purchases responded greatly to price changes. However, recently the change in amount purchased in response to a change in price has been relatively small. On the other hand, the quantity of fishery products purchased has responded more to changes in income than it ever has before. Of course, these observations vary according to the species (Wong, 1970).

Consumer benefits from the demand for industrial fish are more difficult to quantify, since there are essentially two levels of retail purchases. In the industrial market, such rawfish as menhaden and anchovies—both marketed almost exclusively as inedible—are sold directly to feed-fish processors. Fish meal, which then becomes part of the feed for poultry and livestock, is eventually converted into final consumer products ranging from pet food to glues. How to apportion these final product benefits among such constituent inputs as fish meal is an unresolved issue.

A related problem involves apportioning total consumer benefits from all fishery products among specific species or specific estuaries. If economic values are to be assigned to individual estuaries, the fraction of the total supply must be determined.

Besides consumers' surplus which pertains to current demands, there is also "option value" associated with the desire for consumption at some time in the future. This benefit is the price an individual is willing to pay now to preserve his option of consuming a product in the future.

Because option value is not included in current market prices, its contribution to fishery values is either dismissed or neglected by many decisionmakers. While it may indeed be difficult to derive the values, some attempt should be made to include them in a benefit assessment. The omission of option value results in an underestimate of the value of a fishery or estuary, which could seriously imperil attempts to preserve fish habitat for future use.

In recent economic literature (Abel, 1974), other types of benefits have also been identified, although their empirical valuation remains to be investigated. One such measure is "existence value," which is an individual's willingness to pay for society's use or conservation of a resource, even if he does not intend to use it.

A related type of benefit follows from an individual's desire to make the resource available to future generations rather than to himself. This "bequest value," as it is appropriately called, is similar to the willing of estates and large fortunes by parents to their children. These benefit concepts should affect future income streams from estuarine resources, but just how much they add to current values has been neither demonstrated nor even conjectured.

Local and Regional Impacts

There are several approaches to assessing the economic impacts of commercial fisheries. The above discussion of measured and non-measured benefits pertains to the direct gains of personal welfare attributable to the production and (actual or optional) consumption of fish resources. Another economic impact is the indirect or secondary effect on the economy of a local area or region. These impacts result when additional income and employment are generated by the fishing industry in other economic sectors such as service industries and retail stores.

Policymakers are rightly concerned about secondary benefits, since one of their common goals is to protect and encourage economic growth within their political jurisdiction. Employment can potentially be stimulated and tax revenues increased within regions that have an expanding fishing industry.

The magnitude of the secondary benefits depends upon the size of the region as well as the structure of the economy and whether underemployed resources

are available there. In general, the smaller the geographic area, the less likely it is for a region to be self-sufficient in many products. Hence, expenditures will take place outside the region and the benefits will be correspondingly reduced. From the regional perspective, it follows that sales or purchases providing additional income to one area may represent a loss to another. For the nation as a whole, however, the local and regional impacts should be excluded from net benefit calculations as they will, by definition, cancel each other. To local and regional decisionmakers, however, this information is essential in weighing alternative plans to determine priorities for economic development.

Some economists (Prest, 1965) argue that secondary benefits should not be counted as a gain to society. They contend that in a competitive economy, these benefits are reflected by the price of the original good. That is, as the secondary effect of the good increases, its price should rise in corresponding fashion. This assumes perfect factor mobility, wherein gross expenditures for fish resources can be easily shifted to other resource demands. In a full-employment economy there are many opportunities for long-term resource shifting. For the fishing industry, this assumption may not be completely valid in cases where fishermen are immobile or cannot find jobs elsewhere.

EMPIRICAL RESULTS

Published estimates of the economic value of estuaries date back into the 1950's, although most values have appeared within the past several years. Recently the work of Odum and fellow researchers (Gosselink, 1973; Odum, 1968; Odum, 1960) received widespread attention because of the large magnitude of estimates[3] for estuaries along the south Atlantic and gulf coasts. But the most extensive evaluations have been conducted by Massachusetts' Division of Marine Fisheries (Chesmore, 1972; Chesmore, 1972; Chesmore, 1973; Jerome, 1969; Jerome, 1973; Jerome, 1968; Jerome, 1966; Jerome, 1965), one of whose charters is "to establish more precisely the values and relative importance to the fisheries of particular areas."

In Table 1 the economic values of various estuarine areas are compared, and are adjusted to base year 1973 by an exvessel fish and shellfish price index (National Marine Fisheries Service, 1974). Values along the Massachusetts shoreline are based on mean high water levels, but would be 20–100 percent larger if calculated for low water conditions due to the change in total estuarine surface acreage. Moreover, they reflect catch value divided by the total area of surface water. In a highly productive subarea of the San Francisco Bay estuary (Howard, 1973), the yearly revenue for oysters exceeds $500 per acre (in 1973 dollars). It is also interesting to compare values for the same estuary, as reported in different references. Along the Alabama coast, for instance, two estimates differ because of the year in which revenues were observed and the specific fishing grounds under consideration. In Delaware Bay, unit values differ by type of species. Other factors affecting the magnitude of estuarine values are discussed later.

The predominance of estimates along the Massachusetts and gulf coast shorelines substantiates the fact that fisheries here are largely estuarine-dependent. In California, however, more than two-thirds of past coastal marshland has been replaced by land developments. In 1899 the catch of oysters in San Francisco Bay exceeded $2,000,000 (in current money) but gradually declined to barely 0.3 percent of this amount by 1973. Western fisheries have thus moved into deeper waters, so that estuaries are seldom valued. In the Pacific Northwest, anadromous fish species contribute to estuarine values, but they spend most of their lives in ocean waters or spawning streams.

A description of the catch in these estuaries indicates the relative importance of the different species. While shellfish provide the major source of income, there are also instances where eels, bait worms, and finfish are economically quite valuable. A comparison of the estimates in the Merrimack River Estuary, Mass., shows that clams rank first in value by far, although potential sales of bait worms are unexpectedly high at more than $250 per capitalized acre. Even marsh grass has an economic value since it supports the growth of an oyster community although no attempt was made in this report to impute a value for it.

These annual values conceal the long-term contribution of estuarine resources to social welfare. For renewable resources such as commercial fish, economic returns should be comprehended over a sufficiently long time horizon. To compare them with nonrenewable resource values over a single (current) year biases the results in favor of current returns. Consequently, a capitalized value of each estimate is also calculated in Table 1.

Capitalized value represents the amount of capital, in real dollar terms, which must be invested at a

[3] According to these authors, natural tidal marshes along the gulf coast typically have annual returns of $3,000 or more per acre. But only $100 of this amount is related to fisheries, the bulk due to waste treatment costs avoided because of the natural assimilative capacity of the estuarine mixing zone. But intensive aquaculture could increase the contribution of fisheries to as much as $1,000.

Table 1.—Economic values of estuaries to commercial fishing

Estuary	Annual Per Acre Value	Year	Description of Catch	Per Acre Capitalized Value in 1973 Prices	Estuary Area in Acres
Essex Bay MA (Chesmore, 1973)	$256.00	1969	Lobsters and Soft-Shell Clams	$4,104.00	1,261
Entire GA Estuary System (Gosselink, 1973)	9.00	1965	All Commercially Valuable Species Landed in Georgia	218.00	393,000
DE Bay Estuary (Shuster, 1971)	170.00	1956	Oysters	3,990.00	8,000[a] (actually fished)
DE Bay Estuary (Shuster, 1971)	1.18	1956	Oysters	11.80	2,560,000[a]
San Francisco Bay Estuary (Howard, 1973)	563.00	1971	Oysters	5,630.00	4,000[b] (actually fished)
San Francisco Bay Estuary (Howard, 1973)	12.00	1971	Oysters	80.00	300,000[b]
San Francisco Bay (Skinner, 1962)	15.00	1956	Mixed Finfish	396.00	300,000
Entire LA Estuarine System (Gosselink, 1973)	27.00	1970	All Commercially Valuable Species Landed in Louisiana	473.00	2,200,000
Entire FL Estuarine System (Gosselink, 1973)	41.00	1970	All Commercially Valuable Species Landed in Florida	718.00	1,050,000
Beverly-Salem Harbor Estuary, MA (Jerome, 1973)	37.00	1965	Clams, Lobsters, Bait Worms, Finfish	894.00	8,541
Mobile Delta, AL (Beshears, 1959)	2.00	1959	Mixed Finfish, Bait Worms, Shellfish	51.00	50,000
Mobile Bay AL (Beshears, 1959)	13.00	1958	Shrimp and Oysters	286.00	275,000
Corpus Christi Bays, TX (Anderson, 1960)	15.00	1958	Mixed Finfish and Shellfish	370.00	228,541
Merrimack River Estuary, MA (Jerome, 1965)	45.00	1964	Mixed Finfish and Shellfish	977.00	3,050
Dorchester Bay Estuary, MA (Chesmore, 1972)	62.00	1967	Lobsters and Soft-Shell Clams	1,240.00	5,293
Galveston-Trinity-East Bay Estuary, TX (Stroud, 1970)	58.00	1967	Mixed Finfish and Shellfish	1,317.00	333,000
Parker River-Plum Island Estuary, MA (Jerome, 1968)	92.00	1965	Crabs, Clam Worms, Clams, Lobsters	2,158.00	3,581
Annesquam River-Gloucester Harbor Estuary (Jerome, 1969)	116.00	1965	Mixed Finfish and Shellfish	2,817.00	2,237
Hingham Bay Estuary (Iwanowicz, 1973)	26.00	1970	Lobsters and Clams	455.00	7,272
Entire VA Estuarine System (Wass, 1969)	77.00	1968	Mixed Finfish and Shellfish	1,545.00	177,073
Coastal Estuaries Hampton-Seabrook, NH (Fogg 1964)	33.00	1963	Clams, Crabs, Lobsters, and Sea Worms	816.00	3,200
Quincy Bay Estuary, MA (Jerome, 1966)	9.95	1968	Clams, Lobsters and Crabs	100.00	7,313
Waquoit Bay-Eel Pond Estuary, MA (Curley, 1971)	106.00	1968	Quahogs, Bay Scallops and Soft-Shell Clams	100.00	7,313
Lynn-Saugus Harbor Estuary, MA (Chesmore, 1972)	28.00	1968	Lobsters, Soft-Shell Clams, Sea Worms	982.00	6,317
Tampa Bay Estuary, FL (Taylor, 1968)	64.00	1965	Mixed Finfish and Shellfish	1,547.00	3,500
Apalachicola Bay Estuary, FL (Federal Water Pollution Control Administration, 1969)	33.50	1967	Mixed Finfish and Shellfish	810.00	64,000
Great South Bay Estuary, NY (Federal Water Pollution Control Administration, 1969)	50.00	1965	Clams	1,113.00	4,500
Atlantic Coast Estuaries (Stroud, 1970)	71.00	1965	Mixed Finfish and Shellfish	2,716.00	2,328,423
Narragansett Bay Estuary, RI (Federal Water Pollution Control Administration, 1969)	31.00	1965	Mixed Finfish and Shellfish	749.00	108,800
Penobscot Bay Estuary, ME (Federal Water Pollution Control Administration, 1969)	113.00	1965	Soft-Shell Clams	2,512.00	6,645
U.S. Estuaries (1973)	21.00[c]	1967	Mixed Finfish and Shellfish	477.00	29,300,000

[a] The per acre value of $3,990 represents the capitalized worth of only the oyster-producing grounds of the estuary, which in 1956 totaled only 8,000 acres. Taking the entire 2,560,000 acre area of the estuary into account and averaging the total oyster catch value across the entire acreage results in the smaller per acre value of $11.80.

[b] The per acre value of $5,630 represents the capitalized worth of only the oyster-producing grounds of the estuary, which in 1971 totaled 4,000 acres. Taking the entire 300,000 acre area of the estuary into account and averaging the total oyster catch value across the entire acreage results in the smaller per acre value of $80.

[c] The unit value is derived by the authors as the ratio of total U.S. dockside revenues (National Marine Fisheries Service, 1974) adjusted for estuarine-dependency, to the total area of U.S. estuaries (Federal Water Pollution Control Administration, 1969).

Note: All values reflect dependency factor of 2/3 of total catch.

given market interest rate in order to return a perpetual dividend equal to a fixed annual net profit. For example, if a particular estuary provides $100 in net social benefits per year from its fishery resources, then its capitalized value at a market interest rate of 10 percent is $1,000.[4] Capitalized values in Table 1 assume an interest rate of 10 percent as the fair market value of current capital investments. The authors believe this accurately reflects the opportunity cost of capital investment with respect to current market conditions in the private sector. It is not our intention to debate which interest rate may be the more accurate but rather to present the concepts of benefit estimation and some examples of empirical studies of the worth of an estuary as a natural resource.

Once the capitalized landed revenue of the fisheries resource has been calculated, one further step is necessary to derive the net economic rent of the resource. Net economic rent is defined as the difference between the costs of the factors of production (capital equipment, labor, and the returns to management) and the landing revenue. Since the (capitalized) values in Table 1 reflect not only the net economic rent of the resource but also the returns to the factors of production, they overestimate the actual value. Therefore, the share of the landed revenue accruing to the cost factors should be subtracted from the total landed value to arrive at the net worth of the actual fisheries resources. From previously cited remarks, however, some economists prefer to use the total capitalized value as a conservative estimate of consumer surplus, which they consider as the most valid indicator of social benefits.

Statistics on the costs incurred by commercial fisheries are rarely published, and therefore must be estimated in an appropriate manner. A discussion of the methodology and of the difficulty of cost calculations is included in the text whereby given the necessary data and cost factors a more accurate estimate of the net resource value could be undertaken. It is hoped that the issues raised in this paper will eventually result in just such an investigation in the future.

DAMAGES FROM POLLUTION

The biological degradation of estuaries by man-made waste discharges is well documented and is reviewed elsewhere in this report. Economic losses, on the other hand, are seldom published. The inherent difficulty of assigning welfare values to these losses, aside from the more basic problem of estimating natural productivity declines, accounts for large uncertainty in the estimates.

Most values of commercial fishery losses from pollution focus on localized problems, although there are at least three national estimates. Practically all values pertain to foregone landing revenues rather than net welfare impacts. Table 2 depicts the dollar value and geographic area of these losses (Tihansky, 1973). Fish kills are evaluated by assuming that each counted fish is worth $0.10, which is generally a very conservative value for mature commercial fish. Retail losses in Puget Sound are converted into landing price equivalents by assuming a 3:1 ratio of their relative magnitudes. The "Red Tide" scare in New England not only reduced lobster and fish sales by several million dollars but also caused unemployment of fishermen, who would have earned $91,000 in 1972. Other estimates in the Table illustrate the wide variation of effects of waste discharges on a number of estuarine-dependent species, ranging from clams to salmon. In Galveston Bay, Tex., the loss of oyster sales translates into $60 per acre (in 1971).

Table 2.—Estuarine fish losses from water pollution, 1970

Area	Damage ($1,000)	Species Affected
Boston Harbor, Mass.	$5,000	Clam
Chesapeake Bay	8,000	Menhaden
	1,860	Other Finfish
	1,090	Shellfish
Columbia River Mouth	865	Salmon
Galveston Bay	1,930	Finfish [1]
	15	Oyster
Long Island Sound	1,000	Oyster
	225	Clam
Maine Coast	5,000	Clam
Narragansett Bay	1,000	Oyster
Portsmouth, N.H.	2,600	Clam
	125	Oyster
Puget Sound	1,200	Oyster
Raritan Bay, N.J.	8,500	Shellfish
San Francisco Bay	2,600	Shrimp
	2,250	Oyster
	170	Clam
	6,750	Bass, Shad, Salmon [2]
Tampa Bay	2,650	Finfish

[1] Potential loss from oil spills.
[2] Potential loss from inland drainage.

Most estimates in the Table illustrate the wide variation of effects of waste discharges on a number of estuarine-dependent species, ranging from clams to salmon. In Galveston Bay, Tex., the loss of oyster sales translates into $60 per acre (in 1971).

[4] This calculation can be easily derived from the capitalized value formula, $C = V/i$, where C is equal to the capitalized value; V, annual profit, and i, the interest rate. Thus by holding V constant, C will vary inversely with the size of the interest rate. An unrealistically low interest rate, that is, one not reflecting the real rate of return on capital in the market place, would produce a relatively higher capitalized value and overestimate the real worth of the resource.

An estimate not included in the table was the loss of oysters from shellfish area closures in New Haven Harbor, Conn. The foregone cost of small, seed oysters amounted to $578,000 in 1967, but upon maturity they would yield a large potential income of $6,688,000. Annual revenue losses provide an incomplete perspective of total damages. Over the past 65 years, environmental changes along the Connecticut coast have caused declines in shellfish production totalling more than $1 billion (Wong, 1970).[5] Furthermore, the initial effects on decreased fishermen's wages are multiplied throughout the state economy by factors typically between 5 and 10.

National estimates are based on the proportion of shellfishing areas closed by pollution. One study (Bale, 1971) estimates total annual losses of $12 million. This assumes that only clams and oysters are affected since they are immobile and harvested primarily within bays and estuaries. Another analysis (Council on Environmental Quality, 1970), however, assumes that all shellfish including lobsters, shrimp, and crabs are affected by contamination. Its estimate is $63 million based on current closures of one-fifth of the nation's shellfish beds and a corresponding loss of potential revenue. These values assume, contrary to economic theory, that prices remain constant despite large shifts in resource availability. A more recent approach (Tihansky, 1973) measures damages as the consumer surplus foregone by the above shellfish supply losses due to contaminated waters. The national estimate ranges from $24 million for clams and oysters to $38 million if finfish are added to this list of affected species.

FACTORS AFFECTING THE ESTIMATES

Any monetary estimate of estuarine (or fishery) values should be explained with respect to its empirical assumptions. The magnitude of values is a function of a number of determinants, ranging from the extent of fishing grounds to the time span over which the economic impact is calculated. The following factors contribute significantly to these estimates.

Definition of Estuary

The geographic extent of an estuary determines the expected magnitude of catch within its boundaries. While most definitions of an estuary are easily interpreted, there is a lack of unanimity on the most logical choice. Classical opinion holds that estuaries are restricted to the outflow of rivers in a tidal sea, but more recent definitions include nontidal areas so long as the river water noticeably dilutes sea water (Idyll, 1967; McHugh, 1967). The extreme description extends beyond these concepts to include all waters immediately bordering the ocean coastline. But most studies reject the extreme notion in favor of one of the other viewpoints.

Location of Catch

Relatively few fish or shellfish species appear to remain in estuaries during their entire life span. But at least two-thirds of the total catch near the U.S. shoreline spend at least part of their lives here. In some cases, the estuarine habitat serves as a spawning ground, but more frequently it is a nursery ground, densely populated with juveniles and young adults. Estuaries can also provide nutritional value and food sustenance for temporary residents, and they act as the intermediate area through which anadromous (and catadromous) species journey between ocean and freshwater spawning grounds.

Estuaries also have an indirect value of supporting species in offshore water. Rich nutrient loads from the marshes are transported out to sea by tidal flow and ocean current. In addition, estuarine-nursed shrimp and other life forms low in the food chain are an important source of protein and food for a great many predators, including fish. Unfortunately, this valuable function of translating the richness of estuaries into directly consumable resources cannot be quantified without an almost prohibitively expensive research program tracing the flow of energy in a huge ecosystem. In the literature there is a general consensus that all estuarine-dependent species should be included in the value of estuaries, but at least one reference (McHugh, 1967) suggests a downward adjustment of this total to reflect only the biomass added by the inshore region. In no instance is the indirect food-supportive role of estuaries evaluated in any benefit study.

Temporal Aspects of Catch

To obtain a reliable estimate of the abundance of estuarine-dependent fish is most challenging. Species composition and population densities vary by degrees of salinity, temperature, and other physical aspects of the estuary as well as by season or even by a multi-year period. Catch volumes are likely to be higher when species are relatively abundant, but this is not always true. The type of fishing gear used, the ability of fishermen to locate potential catches, the degree of fishing effect from the sport

[5] This estimate is derived as the sum of lost revenues over a 60-year period beginning in 1900. On an annual basis, therefore, the average loss is approximately $15 million.

fisheries, and political restrictions on the availability of fishing grounds are important parameters in the production function. Occasionally, mass mortalities and dramatic fish kills unpredictably alter catch statistics as well.

The problem therefore is to ascertain the "typical" catch rate or other suitable measure of the abundance of commercial species. Most yield estimates in the literature are based on current conditions. But this time frame could lead to biased answers, if the catch was abnormally low during this period or, at the other end of the spectrum, was higher than the mean. In regions where wide variations in catch have been recorded, benefits should be estimated for low and high volumes in addition to the mean or most likely level. The assumptions underlying this range of estimates should be clearly stated.

Unreported Landings

Catch statistics by themselves may not indicate the total volume of fish caught for commercial purposes. Frequently, unwanted fish are discarded back into the fishing ground, while other species or aquatic specimens unfit for direct human consumption may be sold as bait or as a protein supplement processed in various food products. Reported landings represent a minimum for still another reason. Private fishermen fail to report an unknown quantity of catch, which serves as food in their homes or possibly is sold by them locally. In some estuaries this contribution could be very significant. Further, the contribution of U.S. estuaries to foreign catches is uncertain. Assessing the net worth of these landings poses an additional problem because of the different markets and varying conditions under which they are sold. It is conjectured in Louisiana, for instance, that at least 50 percent of the annual shellfish is so destined (Murray, 1974). The relative share of unreported landings is believed to be large in other states as well, although fisheries experts are generally unwilling to estimate this magnitude.

In view of the likely importance of private catch, a confidence interval of benefits should be evaluated for any estuary. The lower bound estimate should reflect reported statistics, while the upper one should include a "guestimate" of catch aggregated over all unreported but commercially-related sources. Of course, the market price of reported landings may be quite different from the economic value of private catch (which need not be processed and distributed, if the fish are consumed directly at the fishermen's residence). Unit benefit values (per fish caught) should thus be sensitive to these market alternatives.

Price-Income Effects

Economic benefits of fishery resources exist only if there is a demand for their consumption or preservation. Because fisheries must deal with a relatively fixed (but renewable) resource, it is especially urgent in light of population growth that the economic impact of demand pressures be predicted. Practically all demand analyses reveal the basic importance of price and income. Since consumer surplus is derived from demand curves, these determinants have a major effect on benefit values over time.

Historically, the consumer has been sensitive to the price of fish products, but with rising incomes this reaction has become far less pronounced. Luxury foods, such as shrimp and salmon, now appear frequently in many households. These responses imply a generally low price elasticity but a high income effect on demand. In benefit calculations over future time streams, therefore, it is important that these responses be considered. If there is reason to suspect, for example, that projected inflation rates will lower real income, demand curves should be adjusted accordingly so that consumer benefits (surplus) can be predicted more accurately.

Level of Optimal Catch

The biological role of estuaries in perpetuating fishery resources is as important to benefit calculations as the impact of consumer preferences. For some finfish and shellfish species, supply shortages are curtailing potentially larger demands for these products by continually pushing up their market prices. On the other hand, there are many underutilized species that could provide additional sources of nutrition to consumer diets.

There are several measures of the supply variable, each of which uniquely affects the magnitude of net benefits. Biologists usually seek to estimate the level of fishing associated with the maximum sustainable yield (MSY), such that the annual gain in species population from recruitment and growth is just offset by natural mortality and fishing catches at a population level that maximizes catch. But economists (Fry, 1962) usually argue that since commercial fishing is motivated by profits rather than physical catch, the more appropriate objective is the maximum economic return to the fisheries and the regional economy. In actual situations, neither of these goals is pursued. Instead, the free entry nature of fishing encourages inefficient use of input factors and through overcapitalization and overfishing, has frequently reduced profits (resource rent) to zero.

All of these yields are likely to fall short of maximizing overall welfare impacts of fishery resources. The MSY and free entry solutions obviously are not oriented toward such an objective. But even the economic rent-motivated approach may be misleading, as it ignores various social values of the fishing sector (since they elude simple quantification). More importantly, it represents a partial equilibrium solution by neglecting optimal benefits in the processing and distribution sectors. Some analysts (McHugh, 1970) conjecture that maximal catch rates might confer advantages on the latter sectors by increasing economies of scale in production. Whether this hypothesis is valid remains to be tested empirically. Until then, net benefits should be calculated twice, bounded above by the MSY solution and below by the optimal net social return.

Several case studies can be cited on the economic returns expected at various levels of fishing effort. A detailed analysis (Gates, 1973) of the New England yellowtail flounder fisheries concluded that the current free entry situation nullifies the total net rent to domestic industry (although net earnings differ by vessel class). However, limited entry and more efficient operations (e.g., fewer vessels) at the MSY point would yield an 18 percent profit rate. From the economically efficient viewpoint, this rate is even higher at 70 percent of total earnings while total catch falls almost 13 percent from the MSY level.

Augmented Production

Complicating the supply level is the likelihood of future aquaculture enterprises and the uncertainty of future markets for underutilized species. With the former alternative, high yields—perhaps several hundred times natural levels—of estuarine species can result by concentrating organic matter as a food source into a small water area. However, such yields depend not only on the quantity of organic matter, but also on the ability of the fish or shellfish to strain food from the water. Some methods of aquaculture are known to have an adverse impact on the estuarine environment, however, and may reduce the natural productivity there. This factor must carefully be weighed when calculating the net benefits from such activity.

In addition, the cost of fertilization or artificial feeding may be prohibitive, as a result of the need for large quantities of nitrogen and other essential nutrients. The inclusion of mariculture yields as a benefit of estuarine resources overlooks the issue of manmade versus natural impacts. Since these benefits could be potentially large, they should be distinguished from natural values unless they evolve from a more intensive use of the current nutritional content of estuaries. In Galveston Bay, Tex., for example, it is believed (Stroud, 1970) that additional shellfishing effort could increase current landings by 50 percent, without exceeding the MSY constraint on natural productivity. From an economic viewpoint, however, this increase is justifiable only if marginal costs of fishing are less than added revenues.

Potential returns from aquaculture are particularly striking and can increase fourfold as the intensiveness of the operation increases. Despite these favorable projections, marine aquaculture in this country is oriented mainly toward developmental and pilot studies, whereas inland freshwater "fish farms" are more popular and in many cases are highly productive. It is projected (Commission on Marine Science, 1969) that such fisheries will control a significant share of the consumer market in 20 to 30 years.

Some notable examples of successful mariculture efforts using scientific management schemes have been conducted in the State of Maine (Dow, 1966). Yields approaching $150,000 capitalized value per acre (in 1973 prices) have been recorded for clam beds. While this value is extraordinarily high, it does indicate that certain highly productive subareas of the estuary can yield several times their normal output of fishery products.

Another means of augmenting current supplies is to market underutilized species or byproducts thereof. The potential harvest adjacent to the U.S. coastal zone is enormous and could easily exceed present production by a factor of 10 (Commission on Marine Science, 1969). Whether these can be economically harvested and processed will depend on individual species. The natural supply of these species should be valued as an optional resource benefit for future consumption.

Unfortunately, supply predictions in the future are beset by a number of uncertain economic and political factors. To include the above supply augmentation schemes in the analysis could thus involve so many ill-founded assumptions as to erase any credibility in the estimates. But certainly these options need to be recognized in the analysis, and their likely impacts on potential value should be compared.

Competing Activities

Another factor influencing the supply function for commercial fisheries is interference from other activities that depend either directly or indirectly on estuarine resources. The above survey of pollution

damages, for example, shows how industries and municipalities have reduced natural stocks of fish or shellfish. Throughout the United States, commercial and residential land developments have been responsible for an acute loss of estuarine habitat for fish and wildlife. Further, it can be expected that future aquaculture activities in the estuary will have some detrimental effects on the populations of surrounding wild species of fish and wildlife.

A more visible challenge to commercial fishing arises from sport fishing interests. In many regions, the high level of expenditures for recreation, and particularly fishing, indicate social benefits derived from these activities. As a result, commercial fishermen in some cases may be faced with dwindling catches and restricted fishing grounds. The corresponding rise in marginal costs could force commercial fleets to move to more productive areas, to change the species mix of catches, or to curtail production and perhaps eventually go out of business. Fishery benefits thus cannot be calculated in isolation of other estuarine values. Implicit in each estimate, therefore, is an assumption on the extent of competing land and water uses.

Distribution of Catch

In many estuaries the annual harvested value of commercial fish is recorded on a unit acreage basis. Averaging total catch in this manner fails to disclose subareas of greater productivity. Because the harvest is unequally distributed, average values thus give insufficient data on setting priorities for the most valuable portions of the estuary.

Variations of landing revenue by estuarine area can be very significant. In Gloucester Harbor, Mass., (Jerome, 1969), for example, the annual income from shellfish is almost $100 per acre averaged over the entire estuary. Yet if this record were restricted to soft-shell clam habitats, the unit value would increase to $240. An even more striking example is provided by the intensiveness of shellfishing in the mouth of the Delaware River (Shuster, 1971). While the harvest value over the entire water surface area was $13 per acre, production was actually restricted to about one-fourth of this area, yielding a unit revenue of $51. But even this estimate of habitat area may be overstated as commercial harvesting take place on a small portion of this region. Adjusting for actual fishing grounds raises the unit value to $170. It is further argued that harvest rates may be less than 10 percent of the actual production in this estuary. Hence, catch and population may differ considerably, which further complicates the projection of fishery values in future years.

Regional Impacts

Arising from direct benefits and costs in the commercial fishing industry are secondary income flows throughout the economy—both on a local and a national basis. Tracing these flows requires a detailed and generally complex input-output analysis of household expenditures and economic sector dependencies within local boundaries, and an account of interregional trade volume and government transactions.

Several references from the literature provide insights on these impacts. In the southern New England region (Rorholm, 1967), the commercial fishing industry was partitioned into these components: fish catching, fresh and frozen fish processing, and fish wholesaling and jobbing. Sales and local value added were estimated for each component, as were general income multipliers ranging from 2.96 for catching to 3.74 for frozen fish processing. In Clatsop County, Ore., (Collin, 1973), the local income multiplier for fish catching equals 1.23, whereas it is 1.81 for fish processing. These values are relatively small because of the county's strong dependence on non-local business. For the Texas marine area (Milroy, 1970), the multiplier for the fishery sector is assumed to be 1.75. It is obvious from these few studies that local impacts vary considerably and depend on the size and industrial composition of the economy, and the extent of marine activities in the region.

CONCLUSION

Some of the most valuable fish resources are dependent on estuarine habitats, with approximately two-thirds of the total dockside revenue of U.S. commercial fisheries identified in one way or another with these marine waters. Yet despite this important life-support function, estuaries have lost more than 7 percent of their fish and wildlife habitat to commercial and housing development over the past two decades (Commission on Marine Science, 1969). In many coastal areas these developments proceeded without any comparison of the socio-economic welfare impacts realized by competing uses of the estuarine area. To preserve remaining habitats from land use encroachments, it is thus important that comprehensive values of natural resources be reorganized and assessed to the fullest extent possible.

The object of this paper was to summarize the state-of-the-art on the estimation of commercial fishing benefits associated with U.S. estuaries. Until now, there has been no attempt to critique or even compile empirical studies on a regional basis. This

survey reveals that a large number of estimates have been published (see Table 1), contrary to the widely held opinion that few exist. Most of these estimates pertain to recorded landings along the New England and the gulf shorelines although several, primarily off the south Atlantic coast, evaluate the potential impacts of increased yield through mariculture techniques.

Despite their large number, practically all of these estimates are conceptually invalid since they measure private rather than social welfare gains. In at least one instance (Tuttle, 1974), however, private revenue (based on the exvessel price of fish) was used as a conservative estimate of the net benefits realized at major phases of the fishing industry. But using this surrogate value, to avoid inherent difficulties of estimating welfare impacts, not only leaves the degree of underestimation unanswered, but also could be an incorrect assumption for other regions. It is therefore misleading and, furthermore, unjustified from the perspective of economic theory, to value estuarine resources solely in terms of market prices.

An additional area of economic evaluation is the contribution that estuaries make to U.S. sport fisheries. It is generally agreed that the benefits derived from this important recreational activity, if quantified, would exceed those of the commercial fisheries. The obvious implication is that the exclusion of sport fisheries values further underestimates the true worth of the estuary.

To close the gap between the conceptual framework and the validity of estimates, more research should be devoted to economic aspects of fisheries. The following recommendations pertain more specifically to this goal:

- Determine economically optimal net rents at the fish catching phase for a wide variety of estuarine-dependent species.
- For various species of fish and shellfish, assess net profits at the processing and distribution phases.
- Derive consumer demand functions at the retail phase, and estimate consumer surplus given current market prices for a selection of fish products.
- Investigate regional differences of the welfare impacts described above.
- Estimate the total biological productivity within an estuary. This value gives a broader perspective than catch statistics on commercial fisheries, since the harvest of natural products from the end of the food chain represents less than 5 percent of total productivity (Odum, 1975).
- Determine the value of sport fisheries benefits derived from the estuary.
- Derive all benefits in a capitalized value context, in addition to their magnitude over the current year.
- Obtain regional estimates and supportive data on the potential of increasing natural productivity in estuaries whether by improved fishing efficiency or other means.
- In each estuary, perform a zone-oriented analysis whereby the most productive areas are identified. Economic values of these areas versus the mean value over the entire estuary should also be compared.

Information associated with these recommendations could assist coastal zone managers in planning economically optimal uses of estuaries. Without such information, the rationale underlying their decisions will remain inadequate. By considering benefits in as comprehensive a manner as possible, the policymaker would proceed with a more balanced perspective of the impacts of estuarine uses on societal welfare. Only in this manner can there be a reasonable assurance of optimizing the benefits of resource allocation.

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ACKNOWLEDGMENTS

The authors wish to thank the following individuals for their guidance and detailed comments of earlier drafts of this study: Fred Abel, U.S. Environmental Protection Agency (EPA); Fred Bell, Florida State University; Ralph D'Arge, University of California at Riverside; Joel Fisher, EPA; John Gates, University of Rhode Island; Jack Greenfield, National Marine Fisheries Service; Michael Hay, EPA; Laurie McHugh, State University of New York at Stony Brook; Philip Meyer, Canadian Department of the Environment; Eugene Odum, University of Georgia; Ken Roberts, National Oceanic and Atmospheric Administration; and George Tononaka, National Marine Fisheries Service.

Andrew McErlean of EPA provided financial support for part of the literature search. Patricia Kelley of the National Geographic Society provided estimates of the total acreage of several estuaries. Susan Penn patiently typed the final manuscript.

CONCLUDING REMARKS

ORGANIZATIONAL ARRANGEMENTS FOR MANAGEMENT OF ATLANTIC COAST ESTUARINE ENVIRONMENTS

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ABSTRACT

Since 1969, the general trend in management of Atlantic coast estuarine environments has been to strengthen state and regional capabilities principally through new federal funding programs. Interstate management entities, with limited exceptions, are not playing an extensive or significant role.

Many approaches are used for estuarine management by the various states. Critical management decisions typically involve specific site-related permit decisions. In many states, these individual decisions are made within a framework of overall state guidelines, policy, or legislative mandate. All states have adopted water quality standards and all but one have wetlands management programs. A few states have adopted strict Coastal Zone Management programs. No states have separate estuarine management agencies, relying instead, on several related agencies or centralized environmental "super agencies."

Coordination is the most necessary element of effective estuarine management. The Coastal Zone Management Act has provided states with the initiative (and funds) to effect a better coordination within their own agencies and with other states on a regional basis.

Estuarine management has improved in the period 1969–1974 as a direct result of increased federal funding supported by a growing awareness of the importance of a quality environment among the general population. The principal factor in estuarine management in the next five to 10 years will probably be local acceptance and support of developing Coastal Zone Management programs.

INTRODUCTION

Status of Arrangements in 1969

In 1969, the Federal Water Pollution Control Administration, Department of Interior, in its "National Estuarine Pollution Study" summarized the status of estuarine management in the nation's estuaries. In respect to federal activities, seven Departments (Interior; Commerce; Transportation; Agriculture; Health, Education and Welfare; Housing and Urban Development; and Defense (U.S. Army Corps of Engineers)) were identified as having the prime impact on management of the nation's estuaries. Table I briefly summarizes the major activities of these departments pertinent to most of the nation's estuaries. Activities of other agencies in these departments and other departments, of course, had at that time (and still do) impacts on the nation's estuaries, but these impacts were usually of a more indirect nature or related to site-specific activities, such as the Atomic Energy Commission or the Federal Power Commission licensing of specific power plants.

The 1969 role of federal activity in estuarine management was described as one of support and technical assistance to the states, regulatory activities within current law at that time, and direct provision of normal federal services, such as navigation aids, channel and harbor maintenance, protective works, and environmental prediction of tides, currents, and weather. "The National Estuarine Pollution Study" urged augmentation of existing federal programs including technical, research, and enforcement programs. In addition, development of a national policy, a stronger means of coordinating federal programs, and a system of planning grants to the states were encouraged.

As with federal management efforts, the tone of "The National Estuarine Pollution Study" was generally critical of states' role in estuarine management. Although a few states were considered to have made significant progress in the area of estuarine management (Massachusetts was singled out as the most advanced state), most were considered to have made little or no progress. The major criticisms leveled at the states in this report were lack of a central organizational/coordinational

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Table 1.—Summarization of Federal activities in estuarine areas in 1969.

Department	Major Agencies	Routine Activities
Interior	Bureau of Commercial Fisheries [1] Bureau of Sport Fisheries & Wildlife [2] Bureau of Outdoor Recreation Federal Water Pollution Control Administration [3] Geological Survey National Park Service Office of Water Resources Research Office of Saline Waters	Permit review in conjunction with Corps of Engineers permit activities; Land and Water Conservation Fund Program; Sewage and Construction Grants; Recreation; various planning and management and resource preservation and development granting programs; water flow data and resource compilation and research activity; participation in River Basin Commission studies.
Commerce	Maritime Administration Environmental Science Services Administration	Port development; mapping and charting; environmental prediction (tides and currents); research.
Transportation	Coast Guard	Law enforcement; aids to navigation; rescue; boating safety; port security; control of shipping.
Defense	Corps of Engineers	Maintenance of navigable waters; permit control of dredge and fill operations; permit control of effluent discharge in navigable waters; harbor construction; shoreline protection.
Agriculture	Soil and Conservation Service Forest Service Water Resources Council	Soil and water conservation projects; sewer and water planning and construction grants; watershed protection; flood control.
Health, Education & Welfare	Food and Drug Administration Bureau of Water Hygiene Bureau of Radiological Health Bureau of Solid Waste Management	Marine health; pesticide monitoring; radionuclide monitoring; public water supply; food and drug purity from marine sources; solid waste disposal; shellfish sanitation program; dumping.
Housing and Urban Development		Planning and assistance in water use; area wide and local planning; water and sewer facilities grants; open space land grants; National Flood Insurance Programs.

Source: "National Estuarine Pollution Study," 1969, pp. V-5 through V-39.
[1] Transferred to National Oceanic and Atmospheric Administration, U.S. Department of Commerce by Reorganization Plan 4 of 1970.
[2] Now U.S. Fish and Wildlife Service, U.S. Department of Interior.
[3] Transferred to Environmental Protection Agency by Reorganization Plan 3 of 1970.

focal point and lack of statewide comprehensive estuarine management plans.

The study expressed the viewpoints of states with regard to estuarine management as falling into three categories:

1. State ownership/management of estuarine resources with federal assistance;
2. Federal-state-local partnership for estuarine management; and
3. Autonomous state management.

The great majority (91 percent) of the states' viewpoints fell into the first category. The preferred role of the federal government in estuarine management was in the areas of financial, technical, and research assistance. Recommendations of the study with regard to the state role called for increased state authority in this area with development of proper organizational arrangements within the states to exercise this authority.

Strong criticism was also expressed of the local government level of estuarine management. Lack of adequate staff and funding capabilities to plan, decide, and implement regulations was highlighted. The presence of underutilized management tools such as legislation, public ownership, public education, permits, zoning, planning, and financial inducements (tax incentives), was noted. Although critical of the local role at that time, the study stressed the crucial role that local governments will have to play in effective estuarine management.

The overall assessment of the effectiveness of estuarine management at all levels of government—federal, state, and local—was disappointing. Several recommendations were made of ways of improving estuarine management at all levels. Coordination, planning, and cooperation were stressed as necessary parts of a successful estuarine management program.

Legislative Federal Developments

The major thrust of federal initiatives in the period since the completion of "The National Estuarine Pollution Study" (1969–1973) has been to strengthen state and regional capabilities in the area of estuarine management, and to make the federal bureaucracy responsive to environmental issues. The National Environmental Policy Act (NEPA) of 1969 (Public Law 91-90) which established the Council on Environmental Quality required for the

Table 2.—Components and functions transferred to the Environmental Protection Agency by Reorganization Plan No. 3 of 1970.

Component/Function	Source
Federal Water Quality Administration	Department of Interior
Pesticide studies	Department of Interior
National Air Pollution Control Administration	Department of Health, Education and Welfare
Bureau of Solid Waste Management	Department of Health, Education and Welfare
Bureau of Water Hygiene	Department of Health, Education and Welfare
Portions of Bureau of Radiological Health	Environmental Control Administration of Department of Health, Education and Welfare
Pesticide functions carried out by Food and Drug Administration	Department of Health, Education and Welfare
Authority to perform studies related to ecological systems	Council on Environmental Quality
Certain radiation criteria and standards functions	Atomic Energy Commission and Federal Radiation Council
Pesticide registration and related activities	Agricultural Research Service, Department of Agriculture

first time in the nation's history the inclusion of environmental considerations in federal decision-making, and the issuing of a detailed statement on the environmental impact of the decision.

Reorganization Plans 3 and 4 of 1970 which established, respectively, the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce, provided focal points for much of the federal estuarine management efforts. In this reorganization, EPA received the components and functions listed in Table 2, and NOAA received the components and functions listed in Table 3. These reorganization plans resulted in primarily three federal agencies or departments having preeminent responsibilities in estuarine management:

1. EPA became primarily responsible for pollution monitoring and control;
2. NOAA became primarily responsible for providing technical and scientific assistance in the area of living resources and environmental prediction; and
3. The Corps of Engineers retained their permit authority in navigable waters.

The Department of Interior retained a strong advisory role in estuarine management through its authority to comment on Corps of Engineer permit applications, spelled out in a memorandum of understanding, dated July 13, 1967, between the Secretary of Interior and the Secretary of the Army. The Department of Transportation retained its strong enforcement role and a major role in oil pollution control (primarily in the area of contingency action) through the Coast Guard.

Major federal legislation relating to estuarine pollution control and management during this period included the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500). The Act presents national goals and guidelines to which the states' programs must adhere, and is considered by many commentators (McMahan, 1972; Rasmussen, 1973; Kuchenbecker and Long, 1973) to be the most effective anti-pollution legislation regarding

Table 3.—Components and functions transferred to the National Oceanic and Atmospheric Administration by Reorganization Plan No. 4 of 1970.

Component/Function	Source
Environmental Science Services Administration	Department of Commerce
Elements of Bureau of Commercial Fisheries	Department of Interior
Marine sport fish program of the Bureau of Sport Fisheries and Wildlife	Department of Interior
Marine Minerals Technology Center	Bureau of Mines, Department of Interior
Office of Sea Grant Programs	National Science Foundation
Elements of U.S. Lake Survey	Department of Army
National Oceanographic Data Center	Department of Navy
National Oceanographic Instrumentation Center	Department of Navy
National Data Buoy Project	Department of Transportation

waterways. Also included is the Coastal Zone Management Act of 1972 (P.L. 92-583), which for the first time in the nation's history stimulates comprehensive estuarine planning and management by the states, providing federal support.

Other acts such as the Ports and Waterways Safety Act of 1972 (P.L. 92-430), the Federal Environmental Pesticide Control Act of 1972 (P.L. 92-516), and the Marine Protection, Research, and Sanctuary Act of 1972 (P.L. 92-532) provide vehicles for protection of the nation's estuaries against pollution by maritime traffic, pesticides, and ocean dumping, respectively, and serve to complement the provisions of P.L. 92-500 and 92-583.

The funding or contemplation of funding provided by federal sources has assisted the states in strengthening their estuarine management programs particularly with regard to planning for pollution abatement. Unfortunately, state advances in the area of pollution control have been hampered by the executive branch withholding (impounding) $3 billion of the $7 billion authorized in the 1972 water pollution control law. The effect of this impoundment is difficult to ascertain precisely. Efforts to have the money released appear to have been successful, so other than loss of purchasing power due to galloping inflation, the eventual effect may be only a delay in attaining desired levels of control.

PRESENT (1974) ARRANGEMENTS OF ATLANTIC COASTAL STATES

Fifteen states contain estuarine waters that open to the Atlantic Ocean. These are grouped into four federal regional districts (Table 4).

Regional planning and coordination is conducted among several groups of states along the Atlantic coast. The most widely acclaimed regional group is the New England River Basin Commission (NERBC). The NERBC has taken an aggressive role in research for regional planning, particularly with respect to estuarine and coastal pollution problems. This group coordinates activities, supports research and education. Financial support for the NERBC comes from two primary sources. The operating budget is provided on a 50-50 basis by the federal government and the seven member states. The states' share is apportioned by a state developed and approved formula. Federal funds are provided through an appropriation to the Water Resources Council. Participation in major studies is supported entirely by federal appropriations. Operating budgets for FY 1971–1974 have been $309,000, $341,000, $376,000, and $417,000 respectively. Major study funds for FY 1971–1973 amounted to $1.4 million (NERBC Annual Reports 1971, 1972, 1973). NERBC has completed several studies of estuarine areas, the most noticeable being the Long Island Sound Regional Study (NERBC, 1971), which has produced a study plan and interim reports on water quality, ecological factors, and erosion and sedimentation; and a series of reports on Boston Harbor's progress towards achieving water quality goals (NERBC, 1970) and its combined sewer overflows (NERBC, 1971).

Table 4.—Atlantic estuarine states (grouped into Federal Regional Districts).

Estuarine States	Federal Regional Headquarters
Maine New Hampshire Massachusetts Rhode Island Connecticut	I. Boston, Mass.[1]
New York New Jersey	II. New York, N.Y.[2]
Pennsylvania Delaware Maryland Virginia	III. Philadelphia, Pa.[3]
North Carolina South Carolina Georgia Florida	IV. Atlanta, Ga.[4]

[1] Also includes Vermont.
[2] Also includes Puerto Rico and the Virgin Islands.
[3] Also includes West Virginia.
[4] Also includes Kentucky, Tennessee, and West Virginia.

Another group, the Coastal Plains Regional Council (CPRC) in the southeastern states has contributed to estuarine management through support of member state research activities and a technical assistance program carried out through the Coastal Plains Center for Marine Development Services. Neither the NERBC nor CPRC has management responsibilities.

Interstate management groups impacting on estuaries include the Interstate Sanitation Commission, the Delaware River Basin Commission, the Potomac River Fisheries Commission, and the Delaware-New Jersey Fisheries Commission. The Interstate Sanitation Commission and the two fisheries commissions, as their names imply, are primarily concerned with pollution and fisheries, respectively, and their regulatory powers are limited to these areas. The Delaware River Basin Commission has broad powers on matters related to water conservation, control, use, and management in the Delaware watershed. The commission has authority to plan, allocate water resources, set standards, and approve all projects which affect water resources. No project which will have a substantial effect on water re-

sources of the Delaware Basin may be undertaken without commission approval. The commission is made up of the governors of Delaware, New Jersey, Pennsylvania, and New York, and the U.S. Secretary of the Interior.

The impact of interstate management entities on estuarine management has not changed significantly since the assessment made in "The National Estuarine Pollution Study" (U.S. Department of Interior, 1969) that these entities had not played an extensive or significant role in overall management of the nation's estuaries. The fisheries commissions, for example, deal with only a portion of the estuarine resources although attempts are made to influence management in other areas such as water pollution control to improve fisheries. The Governor's Task Force on Marine and Coastal Affairs (Delaware, 1972) in fact recommended that the Delaware-New Jersey Fisheries Commission be nullified because of its inability to cope with changing conditions of the resource because of cumbersome provisions for changing regulations. This same task force also pointed out that major problems in the Delaware estuary such as the extreme water pollution between Wilmington and Philadelphia and adverse effects of alterations to the Chesapeake and Delaware Canal were still unsolved despite the regional approach taken by the Delaware River Basin Commission (Delaware, 1972).

Other interstate groupings among the Atlantic states (Table 5) are of an advisory, coordinative, and/or educational nature and influence management of estuaries only through persuasion.

Traditionally, it has been difficult to obtain consent from state legislatures to yield their authority to another body less under their influence such as an interstate compact. It is less difficult for a state legislature to agree to support an interstate planning, advisory, or educational group. The question of a compact for the Chesapeake Bay region is raised periodically. The latest proposal along these lines was made by Senator Mc. C. Mathias of Maryland who suggested the states of Maryland and Virginia consider a Title II Commission for the area (U.S. Congress, 1974). One of the difficulties facing acceptance of this proposal is the degree to which such a commission will appreciably assist in solving the problems in the region. Title II Commissions are only advisory and do interject a third party, the federal government, into the picture. Consideration of the problem of interstate planning and management has become part of overall coastal zone management planning efforts of Maryland and Virginia.

The Chesapeake Bay does present an interesting case study on this matter. The Potomac River Fisheries Commission is a two-state management agency that functions as smoothly as single state fishery management agencies. It would appear that since the two states are the same as would be involved in a joint Chesapeake Bay management agency that little impediment to such an arrangement would exist. Actually, although both states bound Chesapeake Bay and the Potomac estuary, there is a distinct difference. The sharing of the main stem of the bay is sequential rather than contemporaneous as in the case of the Potomac estuary. Each state can relatively easily patrol and control access to the bay waters while this is extremely difficult to do in the Potomac estuary.

Table 5.—Interstate groupings of Atlantic Coastal States related to estuarine management

Group	Members	Powers
Interstate Sanitation Commission	Connecticut New Jersey New York	Regulatory; coordination
Interstate Commission on the Potomac River Basin	Maryland Pennsylvania Virginia District of Columbia West Virginia *	Research; coordination; planning; educational
New England Interstate Water Pollution Control Commission	Six New England states and New York	Planning; advisory
Delaware River Basin Commission	Delaware New Jersey New York Pennsylvania	Coordination; planning; regulatory
Atlantic States Marine Fisheries Commission	All 15 Atlantic states	Coordination; advisory
Potomac River Fisheries Commission	Maryland Virginia	Regulatory
Susquehanna River Basin Compact	New York Maryland Pennsylvania	Planning; coordination
Interstate Environment Compact	50 states and 2 territories	Coordination

* Not an estuarine state.

With the few exceptions noted above, however, estuarine management is a single state function. Within the different states, many different approaches are used for estuarine management. The various components that make up estuarine management are generally not formally coordinated within a state. Coastal Zone Management Act planning and implementation will continue to play a crucial role in effecting formal coordination of estuarine management as part of overall coastal zone management due to the requirement:

> Section 306 . . . (c) Prior to granting approval of a management program submitted by a coastal state, the secretary (of Commerce) shall find that: . . . (2) The

> state has . . . (B) established an effective mechanism for continuing consultation and coordination between the management agency designated pursuant to paragraph (5) of this subsection and with local governments, interstate agencies, regional agencies, and areawide agencies within the coastal zone to assure the full participation of such local governments and agencies in carrying out the purposes of this title. P.L. 92-583

During the period of May through November 1974, all of the Atlantic coastal states received initial planning (Section 305) grants under the Coastal Zone Management Act of 1972 (Table 6). It is too early to expect concrete results in estuarine management as a direct result of these funds. Several states, however, anticipated support under the Coastal Zone Management Act and began coastal zone planning with state funds. Florida, for example, published a state coastal zone atlas (Florida, 1972) in December 1972, which provides in map form a delineation of all coastal areas into preservation (no further modification), conservation (controlled modification), and development (few, if any, state controls) areas.

It must be remembered, however, that some elements of what has come to be considered coastal zone management have been functioning in most states for varying periods. A major task of coastal zone planning and management efforts is the identification and coordination of these elements in support of a recognized, stated goal.

Atlantic Coastal States Organizational Arrangements [1]

CONNECTICUT

Estuarine management in Connecticut is primarily the responsibility of the Department of Environmental Protection. Within the department, parks and recreation, fish and wildlife, forestry, and water and related resources are the responsibility of the Division of Preservation and Conservation; while air and water compliance, solid waste management, and pesticides and radiation control are the responsibility of the Division of Environmental Quality. As in most states, many other departments have direct or indirect inputs into estuarine management. Table 7 indicates some of the various agency responsibilities for estuarine management in Connecticut. Estuarine management is not separated organizationally from the management of other areas in Connecticut. Connecticut has wetlands protective legislation.

[1] Information for this state-by-state summary was obtained primarily from Ponder, 1974; U.S. Department of Commerce, 1973, 1974; Lynch, Patton and Smolen, 1974; and the individual Atlantic state applications for Coastal Zone Management planning (Section 305) grants.

Table 6.—Initial Coastal Zone Management Act of 1972 Planning (Section 305) Grants to Atlantic Coastal States

State	Federal Funding	State Funding	Total
Connecticut	$194,285	$130,339	$324,624
Delaware	194,285	83,334	277,619
Florida	450,000	236,000	686,000
Georgia	188,000	115,400	303,400
Maine	230,000	115,000	345,000
Maryland	280,000	185,765	465,765
Massachusetts	210,000	105,000	315,000
New Hampshire	78,000	39,000	117,000
New Jersey	275,000	137,000	412,000
New York	550,000	275,000	825,000
North Carolina	300,000	200,000	500,000
Pennsylvania	150,000	75,000	225,000
Rhode Island	154,415	77,208	231,623
South Carolina	198,485	100,015	298,500
Virginia	251,044	125,522	376,566

DELAWARE

Estuarine management in Delaware is primarily focused in the Department of Natural Resources and Environmental Control. Four divisions within the department: Environmental Control; Fish and Wildlife; Parks, Recreation and Forestry; and Soil and Water Conservation, are the primary estuarine management agencies.

Delaware is unique among the Atlantic states in that it has passed a Coastal Zone Act (58 Del. Laws, C. 175) which bans all heavy industry and port or dock facilities within two miles of the shoreline not in existence at the time of the Act's passage in 1971. A permit system administered by Coastal Zone Industrial Control Board operating within the State Planning Office of the executive department regulates all other manufacturing uses or expansion of existing heavy industrial uses.

FLORIDA

Florida's administrative structure is unique among the 50 states in that administrative powers are shared by the Governor and a six member independently elected cabinet. Agencies dealing with estuarine management report to the Governor and the cabinet, sitting as a body. Coastal zone planning is the responsibility of the Coastal Coordinating Council within the Department of Natural Resources. The council consists of the executive directors of the Department of Natural Resources, trustees of the Internal Improvement Trust Fund, the Department of Pollution Control, and the Secretary of Administration. The Coastal Coordinating Council functions as an advisory body to the Governor and cabinet in the area of coastal zone management.

Table 7.—Some organizational responsibilities for estuarine management in Connecticut.

Responsibilities	Department				
	Environmental Protection	Health	Transportation	Community Affairs	Commerce
Industrial Development	* R	R	R	R, F	* F, P
Water Quality	* R, F, Rev, P	* R, Rev	P		
Erosion	* R, F, Rev, P	* P			
Coastal Recreation	* F, P	* R	Rev, P	P	* P
Wetlands & Critical Area Preservation	* R, P	* R			* P
Subaqueous Mineral Extraction	* R, P		P		P
Energy	R, F, Rev	Rev	F, Rev, P		P

* Agency directly addresses issue.
R, Regulatory authority.
F, Funding authority.
Rev, Review authority.
P, Planning and promotional authority.

Florida maintains permit and/or base control over most estuarine water or margin uses administered by the Department of Natural Resources or the board of trustees of the Internal Development Trust Fund.

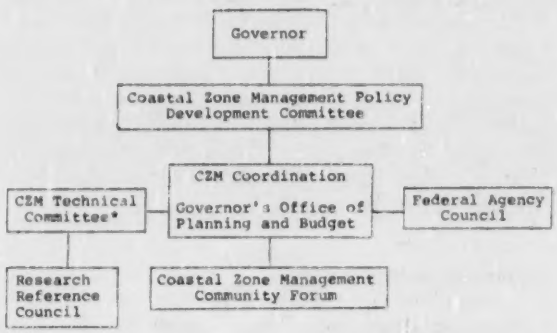
GEORGIA

Estuarine management in Georgia is primarily the responsibility of the Department of Natural Resources. Within this department, the Game and Fish Division is responsible for coastal marshland protection and coastal fisheries management while the Environmental Protection Division is responsible for the water quality standards, water use classification, and the shellfish sanitation programs.

Estuarine planning is the responsibility of a Coastal Zone Management Policy Development Committee which reports to the Governor. The organization for coastal zone management planning in Georgia is shown in Figure 1.

MAINE

Five departments share significant responsibility for estuarine management in Maine. Pollution control is primarily focused in the Department of Environmental Protection which is responsible for licensing of waste discharges and structures in tidal waters or subtidal lands; administration of Maine's Coastal Conveyance of Petroleum Act (including licensing of oil terminals); and enforcement of laws relating to water discharge licenses, air emissions, waste dumping, and water quality laws. The Department of Marine Resources is responsible for fishery law, regulation, and research; maintaining grant, lease, license, and permit records; and monitoring shellfish waters. The Department of Conservation maintains navigational marking and clearances; administers the "Keep Maine Scenic" Law; manages submerged lands; maintains the Coastal Island Registry; and is responsible for watercraft registration and safety. The Department of Transportation houses the Main Port Authority. Monitoring safety of coastal waters for water contact sports and licensing of individual home sewage disposal facilities are the responsibility of the Department of Health and Welfare.



* The CZM Technical Committee consists of:
Department of Community Development
Forestry Commission
Department of Human Resources
Office of Planning and Budget
Georgia Ports Authority
Board of Regents, University System of Georgia
Soil and Water Conservation Commission
Department of Transportation
Coastal Area Planning and Development Commission

FIGURE 1.—Coastal Zone Management (CZM) Planning Organization in Georgia.

MARYLAND

Estuarine management in Maryland is focused in the Department of Natural Resources (DNR) and the Department of Health and Mental Hygiene (H&MH). Other departments such as Transportation (port administration), State Planning (land use planning and state development plan), Agriculture (soil conservation and pesticide control), and Economic and Community Development (waterfront renewal) also contribute to estuarine management.

Estuarine pollution management is exercised by three agencies: the Maryland Environmental Service and the Water Resources Administration in DNR and the Environmental Health Administration in H&MH. The Environmental Health Administration is responsible for water quality and shellfish standards, sewage treatment plant operations, and the statewide health policy. The Water Resources Administration administers the discharge permit system for point sources and is responsible for water quality standards for ground and surface waters. The Maryland Environmental Service is responsible for providing regional and river basin plans for waste water, solid waste, and water supply management.

Most other major estuarine management facets such as wetlands management, shore erosion control, oil terminal licensing, power plant siting, waterway improvement programs, marine policy, fish and wildlife administration, recreation, and coastal zone management are the responsibility of DNR.

A major feature of Maryland's estuarine management program is the Power Plant Siting Act (Anno. Code of Md. Article 96A, Section 23–25) administered by DNR which levees a surtax on electric energy generation in the state to be used for purposes related to power plant operations, particularly ecological baseline studies, monitoring existing operations, long range planning, and acquisition of sites for future power plants.

MASSACHUSETTS

Massachusetts, which was cited by the 1969 "National Estuarine Pollution Study" as having the most advanced estuarine management program, has had a major reorganization of state government. An Office of Environmental Affairs has brought together a number of related agencies. Of particular concern to estuarine management is the Department of Natural Resources (DNR) which has the major responsibility for estuarine management. The responsibilities of Massachusetts agencies with regard to several estuarine management activities are shown in Figure 2.

Overall responsibility for coastal zone management in Massachusetts is housed in the Executive Office of Environmental Affairs.

NEW HAMPSHIRE

New Hampshire's estuarine management programs are not focused in any particular agency or department. Major water supply and water quality programs are administered by the Water Supply and Pollution Control Commission. Coastal zone planning has been assigned to the office of Comprehensive Planning.

NEW JERSEY

All environmental protection in New Jersey is administered by the Department of Environmental Protection (DEP). The Division of Marine Services within the DEP is responsible for coastal zone management, wetlands and shore protection. New Jersey has a Coastal Area Facility Review Act passed in 1973 which divides the coastal areas into various sections, with each section designated for particular purposes. Management divisions affecting estuaries within these designated areas must be compatible with these purposes.

NEW YORK

New York has recently consolidated its environmentally related legislation into one act, the environmental Conservation Law. A marine coastal district has been established which includes all tidal estuarine waters as far up the Hudson as the Tappan Zee Bridge.

The Department of Environmental Conservation is responsible for environmentally oriented estuarine management programs, including coordination of regional and local plans.

NORTH CAROLINA

North Carolina estuarine management and planning agencies are primarily within the Department of Administration and the Department of Natural and Economic Resources.

An Office of Marine Affairs in the Department of Administration established in 1973 has the responsibility of coordination and serving as a communication link with various marine-related programs in North Carolina. A Coastal Resources Commission was legislatively created in 1974 to establish policy,

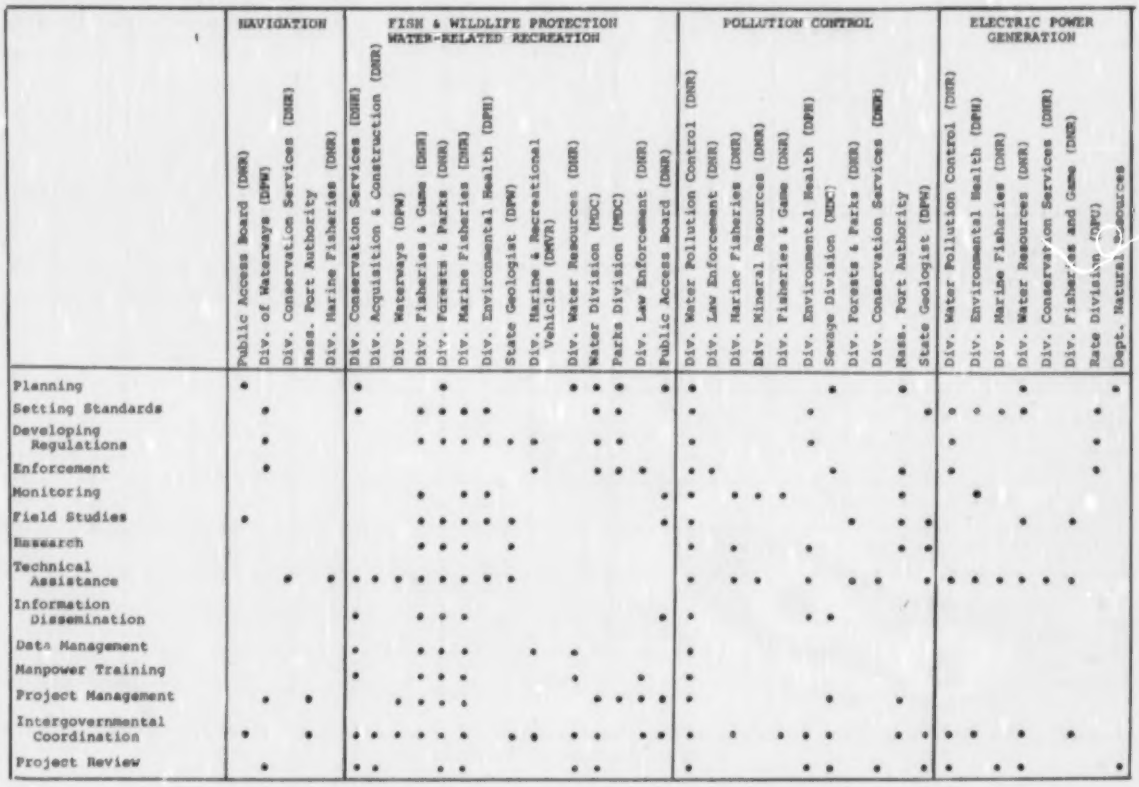


FIGURE 2.—Estuarine management responsibilities of Massachusetts state agencies (adapted from the Commonwealth of Massachusetts' Coastal Zone Management Planning grant to the U.S. Department of Commerce).

develop regulations, and adjudicate coastal area permit applications.

The Division of Health Services in the Department of Human Resources administers the state shellfish sanitation program.

PENNSYLVANIA

Pennsylvania's only estuarine area connected to the Atlantic Ocean is a short section of the Schuylkill River below Philadelphia. The Department of Environmental Resources is responsible for the development of the state water plan, management of the state's land and water programs, and all aspects of environmental control.

RHODE ISLAND

In Rhode Island, management of estuaries is centered in a Coastal Resources Management Council which reports directly to the Governor. This council is composed of the directors of the Department of Health along with representatives of the state legislature and the general public. The Division of Coastal Resources of the Department of Natural Resources provides administrative support to the council. The State Department of Health establishes water quality standards.

SOUTH CAROLINA

The Wildlife and Marine Resources Department and the Department of Health and Environmental Control share the major management role with regard to South Carolina's estuaries. The Department of Health and Environmental Control is responsible for management of water pollution, sewage disposal, shellfish sanitation, water supply, and solid waste disposal. The Wildlife and Marine Resources Department is responsible for fisheries resources, dredge and fill operations, and coastal wetlands. As with many other states, many other agencies

	Economic Development				Resource Utilization					Intrastructure						Pollution				Natural Environment					Environmental Hazard		
	Port Development	Industrial Development	Resort-Tourism	Residential Development	Agriculture	Forestry	Commercial Fishing	Recreation	Mineral Extraction	Transportation	Water Supply	Sewage Disposal	Solid Waste	Utilities	Power Plant Siting	Water	Erosion Sedimentation	Dredge & Fill	Spoils Deposition	Coastal Wetlands	Beaches/Dunes	Wildlife Habitats	Unique Ecosystems	Scenic Areas	Flood Zones	Hurricane Impact Zones	Shoreline Development
Division of Administration		P								P	P	P				P			P								
State Development Board	P	PT			T				T	P		T			P				D								
State Highway Department										PM DR							D	D			D						
Land Resources Conservation Comm.				T	P T	P T			PM R		PM R						PM T								P T		
Wildlife & Marine Resources Dept.			T	T		T	PM TR	PM R								P		T R	TR	PM DT R	PT	PMD TR	PM				P
Water Resources Commission				T			P				PM R	P M				P	PM		P	PT R	P	P	P	P	P	P	P
Parks, Recreation, and Tourism			PM DT					PM R																			
Commission of Forestry						PM RT																					
Dept. of Health & Environmental Control		R	R	R			R				R	R	MR		R	PM TR				PR	R						PR
State Ports Authority	PM DR									PM DR																	
Public Service Commission				R						R	R	R		PM R	PM R												

FIGURE 3.—South Carolina: state involvement in estuarine management. P, planning; T, technical assistance; M, management; D, direct development; R, regulation.

contribute to estuarine management. Figure 3 indicates the contribution of South Carolina agencies to estuarine management.

VIRGINIA

Thirty-seven entities have been identified which play a role in state or regional level estuarine management (Laird, 1974). Some have only minor roles, and some occur within the same department under a unified administrative head. These entities have been broken down into six categories as shown in Table 8.

Principal management responsibility rests at present with the Virginia Marine Resources Commission which manages the state's marine and estuarine fisheries. The commission has review authority over wetlands permits, and initial authority over subaqueous permits or leasing for activities affecting estuarine bottoms, including oyster leases, dredging, and subaqueous mining. The State Water Control Board is responsible for water quality and water quality management. The Department of Health also has permit authority in the field of marina sanitation and through its Bureau of Shellfish Sanitation administers the state shellfish sanitation program.

Virginia's wetland management laws (Title 62.1, Ch. 13, Code of Va.) are strongly oriented towards local management. If localities choose (and most have so chosen), initial permit approval of permitted activities is the responsibility of a local wetlands board. The Marine Resources Commission serves as an administrative board of appeals for challenges to local decisions.

The Marine Resources Commission and the State Water Control Board are bodies made up primarily of informed, knowledgeable citizens not otherwise connected to state government. A commissioner of marine resources is appointed to serve at the pleasure of the Governor and serves as chairman of the Marine Resources Commission and its chief executive officer. The other members of the Marine Resources Commission are appointed by the Governor for fixed terms. The State Water Control Board is administered by an executive director. Permit disposition authority rests in these boards, and all decisions related to permit activities must be made in meetings open to the public.

Table 8.—Entities of state government with planning, management, or scientific and engineering responsibilities in estuarine management in Virginia (after Laird 1974)

I. Departments with Overview Responsibility

Office of the Governor
Council on the Environment
Office of the Attorney General

II. State Agencies Concerned Primarily with Estuarine and Coastal Areas and Adjacent Marine Areas

Marine Resources Commission
Virginia Institute of Marine Science
Department of Health
Bureau of Shellfish Sanitation
Virginia Port Authority

III. State Agencies Which Have Responsibilities in the Coastal Zone Which Directly Affect Estuarine Management

State Water Control Board
Commission of Game and Inland Fisheries
Department of Conservation and Economic Development
Division of Parks
Commission of Outdoor Recreation
Division of Industrial Development
Virginia Soil and Water Conservation Commission
Division of State Planning and Community Affairs
Virginia Department of Highways
Department of Agriculture and Commerce
Department of Health
Division of Engineering
Bureau of Sanitary Engineering
Bureau of Solid Waste and Vector Control
Bureau of Industrial Hygiene
Division of Local Health Services
State Corporation Commission

IV. State Agencies Which Have Responsibilities in the Coastal Zone Which Indirectly Affect Estuarine Management

Department of Conservation and Economic Development
Division of Forestry
Division of Mineral Resources
Division of Mined Land Reclamation
Virginia State Travel Service
Historic Landmarks Commission
Virginia Outdoors Foundation
State Air Pollution Control Board

V. Intrastate Agencies Authorized by the Code of Virginia but Which Are Supported by Local Funds and Have an Impact on Estuarine Management

Hampton Roads Sanitation District Commission
Northern Virginia Regional Park Authority
Virginia Beach Erosion Commission

VI. Interstate Agencies Relevant to Estuarine Management to Which Virginia is a Party

Potomac River Fisheries Commission
Atlantic States Marine Fisheries Commission
Interstate Commission on the Potomac River Basin

Virginia is unique among the Atlantic coastal states for having an estuarine and marine state research laboratory, the Virginia Institute of Marine Science, which is a separate state agency coequal with the management agencies within the state apparatus. In most states, the estuarine research programs are usually subordinate arms of the management agencies or conducted through formal or informal arrangements with the state university system. The Virginia Institute of Marine Science, however, is independently chartered by the Code of Virginia (Title 28.1, Chapter 9). With an independent charter and separate legislative mandate, the Virginia Institute of Marine Science is able to influence estuarine management practices independent of direct pressures from management agencies.

Coastal zone coordination in the Commonwealth of Virginia is the responsibility of the Coastal Zone Advisory Committee, co-chaired by the Department of State Planning and Community Affairs and the Institute of Marine Science. Other agencies making up the advisory committee are the Division of Industrial Development, the Commission of Outdoor Recreation, the Marine Resources Commission, the State Water Control Board, the Commission of Game and Inland Fisheries, and the Department of Conservation and Economic Development. State level coordination between state agencies is being focused in a developing secretariat which reports directly to the Governor. At present, each state agency reports to a secretary. The majority of agencies which have a major role in estuarine management report to the Secretary of Commerce and Resources.

SUMMARY

As can be seen by this brief review of state programs, many approaches are used for estuarine management among the various states. The critical management decisions which impact the estuarine areas usually involve specific site-related permit decisions. In many states, these individual decisions are made within the framework of overall state guidelines, policy, or legislative mandate.

All but one of the Atlantic states (South Carolina) have adopted specific wetland management programs; all have adopted water quality standards; and some (Delaware and New Jersey, in particular) have adopted strict coastal area zoning programs.

Table 9.—Summary of estuarine related State Land Acquisition Authority

State	Agency	Purpose	Authority
Connecticut	Dept. of Environmental Protection	Wetland Acquisition General Purposes	C.G.S.A. 26-17a C.G.S.A. 22a-25
Delaware	Dept. of Natural Resources & Environmental Control	Parks	D.C. 7-5802
Florida	Water Management Districts	Wetland & Water Management	F.S. 373-139
Georgia	State Forestry Commission	Forests	G.S. 43-207
Maine	Board of Environmental Protection Commission of Sea and Shore Fisheries	Wetlands Acquisition Flats & Waters for Scientific Purposes	M.R.S.A. 12-4701 M.R.S.A. 12-3701
Maryland	Dept. of Natural Resources	General Purposes	M.C.A. 66C-186
Massachusetts	Dept. of Natural Resources	Coastal Wetlands Wildlife Sanctuaries State Parks & Forests	M.G.L.A. 130-105 M.G.L.A. 131-7 M.G.L.A. 132A-2A
New Hampshire	Dept of Fish & Game	Coastal Wetlands	N.H.R.S. 483-A:1
New Jersey	Commissioner of Conservation & Economic Development	Wetland Acquisition	N.J.S. 13:8A:4 & N.J.S. 13:8A-24
	Hackensack Meadowland Development Commission	Wildlife Habitats Wetland Development	N.J.S. 13:1B-15-5 N.J.S. 13:17-6(g)
New York	Dept. of Environmental Conservation	Wetlands & Forest Preservation Fish & Wildlife Management	L.N.Y. ECL §260 L.N.Y. ECL §10501
North Carolina	Dept. of Conservation and Development	Natural & Scenic River Areas and Estuarine Areas	S.N.C. 113A-34
Rhode Island	Dept. of Natural Resources	Wetlands Acquisition	R.I.G.L.A. §2-1-15
South Carolina	No Programs		
Virginia	Cities, Counties, Towns Various State Agencies Virginia Outdoors Foundation Commission of Outdoor Recreation	Federal Water Resource Development Projects Open Space Lands Open Space Lands Scenic Rivers Areas	Va. Code 62.1-150 Va. Code 10-152 Va. Code 10-163 Va. Code 10-175

No states have organized separate estuarine management agencies which exercise all management functions. Within most states, estuarine management is the function of agencies which exercise related management functions on a statewide basis. Some states have centralized environmental management into a single "super" department. In these departments, there are often separate divisions which deal with marine resources, but estuarine water quality management functions are usually the responsibility of a division or agency with statewide authority.

At the opposite end of the spectrum from the "super" department exercise of estuarine management is the private "citizen board" concept of management decisionmaking used in Virginia at both state and local levels.

State overview in Rhode Island is by a board made up of ex officio agency heads, state legislative representatives, and private citizens, while in Florida this authority is held jointly by seven elected officials, the Governor and the independently elected cabinet. In addition to permit systems, another tool available to estuarine managers is land acquisition. All Atlantic coastal states have some type of land acquisition authority relevant to estuarine management. These are listed in Table 9.

It is apparent from the multiplicity of agencies with managerial responsibilities that coordination is a necessary element to effective estuarine management. Coordination of environmental regulatory activities has been achieved in several states by centralization of agencies into a super agency. This still, however, leaves the problem of activities which have a measurable impact on estuaries but which are not directly regulated by environmentally oriented agencies.

The Coastal Zone Management Act has provided the initiative to states to effect better coordination of those activities important to sound estuarine management. Although not devoted solely to estuarine management, coastal zone management encompasses all aspects of estuarine management. Improvement in this coordination should be apparent in the very near future.

As mentioned earlier, all Atlantic coastal states are participating in the planning phase of the Coastal Zone Management Act. All states received planning

grants during 1974. Because of the recency of these planning grants, there has been insufficient time to produce specific accomplishments.

State preparations anticipating funding of the CZMA have, however, resulted in formation of either legislatively or executively mandated interagency committees, commissions, councils, or task forces in most states. The CZMA guidelines strongly encourage management at the lowest possible level of management, primarily localities, within, however, state and federally agreed upon principles. The great advantage to the states in developing and adopting an approved CZM program is that once approved by the Secretary of Commerce, the state plan also becomes the guideline for and is binding upon federal programs operating in state coastal areas.

The success of estuarine management programs in future years probably depends upon the success of developing the state-local coordination and cooperation necessary to implement developing coastal zone management plans.

Experience in various states differs as to the effectiveness of local control over environmental matters. In Virginia, local management of wetlands is considered to be successful to date (the Virginia Wetlands Law became effective July 1, 1972), and is being studied as a possible model for coastal zone management within the state.

Estuarine management, particularly as exercised through permit programs, receives much criticism from both environmentalists and developers. The major criticism of both sides is the multiplicity of permits required for a single authorization to proceed with a proposed project. Frequently advocated by both groups are "one stop" permit systems, each side of course assuming "one stop" systems will favor its position. Until a different system is devised which will adequately assess an activity's impact on the various facets of estuarine management, however, a "one stop" system will probably not serve the best interest of the citizens of a state taken as a whole and divorced from particular advocacy roles in a given controversy.

It is unlikely that agencies will be created within the states' organizational frameworks which will function solely or primarily as the manager of a state's estuarine areas. What can be expected is an increasing awareness of the need for closer coordination and cooperation between agencies serving planning, management, and advisory roles in estuarine areas. This need has already been recognized by most states and several have begun to effect this coordination. The next several years will see marked improvement in this area, although there will be difficulties in reconciling federal, state, and local goals, responsibility, and authority. These difficulties, with application of the emery powder of federal funding, will be smoothed sufficiently so that more effective management of estuarine systems will be developed.

Estuarine management has improved in the period 1969–1974. Much of this improvement is the direct result of increased federal funding supported by the general awareness of the importance of a quality environment in the average citizen. Care must be exercised, however, that "ecological fervor," unaccompanied by a sound educational program, does not create an environmental backlash. The reverse is also true, however, that care must be exercised to ensure that temporary crises (of long or short duration) such as the energy squeeze of the early and mid-1970's, are not used as an excuse to dismantle the sorely needed apparatus for environmental concern that has been and is being constructed. It has become apparent to taxpayers that a quality environment is expensive. Without well-documented, understandable evidence that suggested pollution control methods are necessary, public support will not be available and environmental quality will not be maintained or improved.

The Coastal Zone Management Act of 1972 recognizes many of these problems and the regulations implementing the program emphasize the need for developing citizen awareness, participation, and support.

A critical factor in future estuarine management will be the roles of federal, state, and local management agencies. Unfortunately, there is little data available from which to deduce the exact mix of responsibilities which will ensure success. The general approach of the Coastal Zone Management Act—that of a state program developed under federal guidelines which, when federally approved, provides the criteria for federal actions in the region—is readily acceptable at the state level. Still to be determined is the acceptance of possible state constraints on certain federal agencies and even more important, the acceptance by localities of the state plan.

The principal factor in estuarine management improvement in the next five to 10 years will be local acceptance and support of coastal zone management.

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EVALUATION OF WATER QUALITY IN ESTUARIES AND COASTAL WATERS

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ABSTRACT

Estuaries and coastal waters, comprising less than 5 percent of earth's surface, are under ever-increasing pressures from growing populations and demands. Yet these complex and dynamic waters are the key to preserving the viability and productivity of the oceans. Maintenance of their quality is vital to man and his future, causing much concern, especially in the United States. Consequently, considerable research, legislation, and other efforts oriented at improving management of estuarine and coastal waters have gone forward in the last 10 to 15 years. These are discussed in this chapter.

Despite all these efforts, the condition of estuarine environments and resources continues to decline. Several factors appear to be causal. The "state of the art" for control of quality in estuarine and coastal waters must be rapidly improved to reverse the downward trend. Recommendations are made.

As these improvements are accomplished, we will slow and eventually stop, even reverse, the degradation of these vital waters. While making control procedures more accurate and precise, we must also reduce the economic and social costs of controls without lessening their effectiveness.

INTRODUCTION

Historical

Humans and human activities have long been concentrated on the shores of the seas, or along the tributaries which empty into those seas. Given this shoreward distribution of a rapidly multiplying people and their burgeoning societal activities, it is small wonder that we are now greatly disturbed over the worsening condition of the coastal waters and tidal tributaries fringing the oceans of earth.

Concern with quality of the environment focused early on its decline in natural waters. Recognition of atmospheric problems such as contamination of air by heat or chemicals and the possibility of unintentional weather modification, developed later. Probably because they are more easily damaged and more readily observed, upland brooks, small rivers (running waters), and ponds and confined lakes (still waters) called for and received attention first. Later, the larger upland rivers and the Great Lakes began to show regular fish kills and other signs of degradation. Thus, much of the early effort at pollution abatement by science and technology, government and industry was devoted to these essentially upland waters. Only in recent decades have the great tidal tributaries, with their massive fresh and saline reaches, and the coastal waters of the world's seas and the vast oceans, themselves, been attended. The sights and smells of pollution, long apparent in natural inland waters, appeared in most estuarine and oceanic waters very late. Awareness that the oceans and seas of earth are not as remote or inviolate as formerly believed has been slow in coming compared with man's ability to use, to exploit, and to pollute.

It is now clear that control of the condition of oceanic waters will depend primarily upon achieving reasonable control over estuaries and other coastal waters. Additionally, control of coastal waters is necessary in and of itself because it is these waters which most affect man and it is important to maintain an adequate environment for human society.

Belated though awareness of estuarine and coastal waters may have been, much attention has been given them since the 1960's when the strong concern manifesting itself today surfaced and the Water Quality Act of 1965 (PL 89-234), the Clean Water Restoration Act of 1965 (PL 89-753), and the National Environmental Protection Act of 1969 (PL 91-190) came into being.

Legislation aside, concern has also been apparent in the growing number of publications relating to environment, its relation to man, and to the worsening status of many environments and resources. Many governmental groups have been commissioned to consider these problems at all levels—local, re-

gional, state, interstate, federal, and even international. Reports have been written, new legislation passed, and organizations established and modified. Unfortunately, reorganization has occurred so many times as to make some agencies unstable and render it difficult for them to accomplish their objectives. For example, because of its changing and confusing organizational milieu, progress and improvement of the Environmental Protection Agency (EPA) has been slowed.

A large number of major studies of the nation's estuarine systems and of individual estuaries have been conducted since 1960 along with a host of lesser, but useful smaller works. See, for example, (Lauff, 1967), (USDI, 1969), (USDI, 1970), (Stroud, 1971), (Chabreck, 1973), (Clark, 1974), (Odum et al., 1974) and many others.

Manifestation of Interest by Legislative Action

Among the landmark federal enactments which have resulted from this growing awareness and concern for tidal waters have been:

1. *The Water Quality Act of 1965* (PL 89-234) which among other things, initiated the National Water Quality Standards Program [Sec. 10 (c)].

2. *The Clean Water Restoration Act* of 1966 (PL 89-753), which focused on problems of maintaining and restoring quality and uses of the Nation's surface waters. Additionally, in that act the Secretary of the Interior was directed [Section 5 (g)] to study nationwide problems of estuarine pollution. The resultant 3-year effort yielded a very interesting report submitted to Congress in November 1969.

This three volume report was entitled, "The National Estuarine Pollution Study" (USDI, 1969). Noteworthy among its recommendations was development of a comprehensive national coastal zone management system. (This recommendation, seconded by many other study groups, has been acted upon partially by enactment of PL 92-583, The National Coastal Zone Management Act of 1972).

3. *The Marine Resources, Engineering and Development Act* of 1966 (PL 89-454), which focused attention on marine waters and their resources, environments, and uses by society. It also directed: a) evaluation of and improvement in the federal efforts in ocean affairs, and b) a comprehensive review of all ocean-oriented matters. This review was designed to lead to development of a comprehensive national effort to better control, utilize, and preserve the resources and environments of marine waters.

The first responsibility was given to the National Council on Marine Resource and Engineering Development (NCMRED—also known as The Marine Science Council), a federal body consisting of the several departmental Secretaries, the Director of the National Science Foundation, the Chairman of the Atomic Energy Commission and chaired by the Vice President. Dr. Edward Wenk, Jr. was its first executive secretary. A series of annual reports was issued by the Council under the general title, "Marine Science Affairs," with appropriate dates and subtitles (cf. References). One of its four interagency committees, the Committee on Multiple Use of the Coastal Zone, helped focus attention on the fragile area called the coastal zone in various publications and reports and in doing so, joined others in contributing to that developing national program.

The task of conducting a comprehensive nationwide review of all ocean-oriented matters (the last charge mentioned above) fell to the civilian-composed Commission on Marine Science and Engineering Resources (COMSER—sometimes called the Stratton Commission after Dr. Julius A. Stratton, its chairman). This commission expired at the end of a fruitful 3-year life that resulted in a series of comprehensive reports. The summary volume of the four volume set entitled, "Our Nation and the Sea," is an effective distillation of the entire national marine effort to that point.

The commission found great need for considerable attention to the pressured and deteriorating coastal zone and its recommendations for correction form one of the strongest foundations for the current emphasis on the margins of the sea. With those groups mentioned above, the commission contributed significantly to the Coastal Zone Management Act.

4. *The Estuary Protection Act* (PL90-954) reiterated Congress' awareness of the critical nature of coastal waters and directed the Secretary of the Interior "to conduct an inventory and study of the Nation's estuaries and their natural resources" in cooperation with the states.

This study, authorized in August 1968, and funded initially in July 1969 was completed and resulted in a report entitled, "National Estuary Study." Its seven volumes were transmitted to Congress in January 1970 (USDI, 1970). They, too, concluded that the estuarine zone of the United States is a critical environmental and resource area and recommended stronger efforts to manage it wisely, focusing the management responsibility and capability in the states.

5. *The Federal Water Pollution Control Act Amendments* of 1972 provided for establishment, publica-

tion, and, where necessary, revision of comprehensive water quality criteria, among other provisions. Accomplishments and offshoots of this legislation are discussed in greater detail below.

Special Studies and Reports

While these legislative efforts came into being and the activities they called for were pursued to fruition, the Federal Water Pollution Control Administration (FWPCA—now EPA) of the Department of the Interior has established the National Technical Advisory Committee on Water Quality Criteria (NTAC). The body, which was advisory to the Secretary of the Interior, was developed in response to Paragraph 3, Section 10 of the Federal Water Pollution Control Act as amended by the Water Quality Act of 1965. The Committee, named in early 1967, worked vigorously throughout the year and submitted its report to the Secretary in April 1968.

The work dealt extensively with problems of maintaining the maximum utility and quality of estuarine and coastal waters and presented a large number of water quality criteria recommended for use in the management of those waters. These criteria were supposed to form the basis for new water quality control standards, and they did! Both the criteria and standards have been in widespread use since.

In 1971 the Environmental Protection Agency, anticipating the Amendments of 1972 to the Federal Water Pollution Control Act, commissioned another examination of the status of knowledge of surface and ground waters and the elements related to quality. Under a contract to the National Academy of Sciences-National Academy of Engineering (NAS-NAE), several subcommittees comprising the overall Committee on Water Quality Criteria of the Environmental Studies Board of the National Research Council (NRC) were established to review and, if necessary, revise the water quality criteria previously developed. Its report entitled "Water Quality Criteria 1972" was completed in 1972 but not made widely available until recently, (NAS-NAE, 1973)[1].

As indicated above, the NAS-NAE effort was undertaken as a contractual obligation to EPA. Whether the different status of the NAS-NAE appointment group, as contrasted with the old NTAC, which was an official advisory committee reporting to the Secretary of Interior, will have an effect on the ultimate development of revised standards from these criteria, will be interesting to see. It is too early to tell. As will be shown below, EPA has responded by utilizing a large number of these criteria directly in developing their own proposed criteria (U.S. Environmental Protection Agency, 1973).

[1] Though the title indicates that the report was completed in 1972 internal evidence in the "Blue Book" indicates that it was not actually printed for circulation until early 1973. It was not widely available until then.

Other Activities

There have been a number of other significant activities relating to problems of coastal and estuarine environments which impinge upon assessment of the status of those waters and of the seas and oceans into which they empty. Among them have been the various pollution-related research efforts of the National Science Foundation through its projects administered by the International Decade of Ocean Exploration Program. Several useful publications have resulted. See, for example, Goldberg (1972b), and Duce, Parker, and Giam (1974). Too, NSF's Research Applied to National Needs Program (RANN) has contributed significantly by supporting water quality-related activities in various estuarine and coastal areas. RANN has also sponsored several review activities such as workshops and symposiums devoted to problems of coastal waters and lands. As examples see: "The Water's Edge: Critical Problems of the Coastal Zone," (B. H. Ketchum, ed., 1972) and "The Chesapeake Bay: Report of a Research Planning Study," (Beers, et al, 1971).

The massive report in four volumes prepared for FWPCA as part of the National Estuarine Pollution Study of 1968 and 1969 and published by the Conservation Foundation under the general title, "Coastal Ecological Systems of the United States" (Odum, Copeland and McMahan, eds., 1974), is worthy of special note here as are the 1971 reports of the NAS-NRC Ocean Affairs Board, "Marine Environmental Quality," and NAS-NAE Committees on Oceanography and Ocean Engineering (NASCO and NAECOE) "Waste Management Concepts for the Coastal Zone," (NAS-NRC, 1970).

All of these activities have served to focus attention on the nation's coastal and estuarine waters and on the need to understand and manage these waters effectively so that they will be of maximum utility to society and will be available in undiminished quality and quantity to posterity. They have also served to establish a stronger basis for developing management efforts and to indicate where current knowledge and managerial ability are weak.

Purposes

Some aspects of the legislative and technical history of the effort to manage the quality of estu-

aries and coastal waters have been presented above. Important as it is to understand these historical aspects, the overall purpose of this chapter is a general evaluation of water quality in the nation's estuaries as a whole. In doing so, we seek to examine the current status of the national estuarine system. This will be done in relation to modifications in quality, quantity, and utility of the resources and environments of those coastal waters resulting from the activities of man. In this effort the intention is to consider existing quality, trends in quality, existing water quality criteria, and the state of the art in establishing and evaluating the same. Ability to monitor will be examined also.

THE WATERS IN QUESTION

To accomplish the purposes projected above, we must first define the various components of the waters under consideration and examine them in some detail. It is only in the light of adequate factual knowledge about these waters that effective management can be cast!

Estuarine and Coastal Waters

While most of the legislation previously mentioned especially referred to and used the terms estuary, estuarine and estuarine zone it soon became clear that the coastal waters, those on the coast of the open ocean, also were involved. They, too, are intermediary between land and land drainage and the seas and oceans. Both estuaries and coastal waters must, therefore, be considered, if our management system is to be complete in its coverage.

ESTUARINE WATERS

The word estuary usually denotes a semi-enclosed body of water opening into or debouching from the ocean, receiving ocean waters and tides and, generally, contributing freshwater to the seas. This definition is rather broad. Some, for example Pritchard (1967), construe it more narrowly, restricting the term to those areas or reaches of tidal tributaries within which ocean waters are measurably affected by or mixed with freshwater from upstream.

Much discussion has been devoted in the literature to the various categories into which the estuaries and coastal waters of the world may be divided. A number of classification schemes for estuarine waters have been devised and published in various scholarly and technical papers, such as Williams (1962), Pritchard (1967), Clark (1974), and Odum, Copeland, and McMahan (1974). Many of the systems presented in those works are quite significant scientifically. While all of them are interesting and some are useful to management, a complete review of classifications is beyond the scope of this report. For our purposes it is sufficient to note the existence of the different ones, adopt one with utility, and move on.

Along with others who have considered the problems of managing the quality of waters of the coasts, I have found it expedient to simplify terminology. Consequently, in this essay the word estuary is construed broadly, covering all semi-enclosed basins and tributaries which interact with the world's seas and oceans (including the tidal bodies frequently classified separately, such as fiords, tidal rivers to the upper limits of tide, lagoons, brackish and saline bays and sounds, and others).

COASTAL WATERS

For all open coastal situations the term coastal waters suffices. Both estuarine and coastal waters interact with the land, with surface runoff and subterranean aquifers, and with man and his activities and properties. Both receive his effluents directly and indirectly. Both retain or transmit them to the sea or to the bottom. To protect the oceans, husband their qualities and uses, and properly serve present and future societies both must be effectively understood and managed. Adequate understanding is absolutely necessary for management! See especially the background materials commenting on these points presented in the NAS-NRC paper "Waste Management in the Coastal Zone," (NAS-NRC, 1970, p. 2).

Characteristics of Estuarine and Coastal Waters

The oceans, themselves, and the highlands (or fastlands) comprise about 95 percent of the surface of the earth. The waters and adjacent lowlands which interface between these two major geographical realms make up less than 5 percent of the total area of the globe. This is the "coastal zone." Comparatively minor in area, this small portion of interacting land, water, and air is highly critical. It is all-important to the condition and welfare of land and sea and of society. Like all such transition zones it is a dynamic and changing fraction—a zone of high energy flux.

FEATURES OF ESTUARIES

As indicated, many attempts at definition have been made and several classifications published. The simple definition utilized here, i.e. estuaries are bodies of water regularly connected with the ocean, within which measurable quantities of ocean water occur and/or which experience ocean tides, encompasses all known types occurring around the United States, from the several hypersaline lagoons (which receive only limited amounts of freshwater, have weak flushing action and contribute salty water to adjacent coastal areas) to the mighty estuary of the lower Mississippi River (which injects massive amounts of freshwater, sediments, and other materials into the northern Gulf of Mexico).

The fringing coastal bays, sounds and lagoons protected behind the barrier islands of the Atlantic and gulf coasts and the fresher, more elongate and frequently larger tidal bays and tributaries of all coasts also fall within the definition. The Laguna Madre of Texas, the Carolina sounds, the seaside bays of Virginia, Maryland, Delaware, New Jersey, and Long Island are examples of the former (fringing coastal bays and sounds). Cook Inlet, the various fiords and river mouths of Alaska and the Great Northwest, Mobile Bay, Tampa Bay, Wynyah Bay, Charleston Harbor plus its entering tidal tributaries, the Ashley and the Cooper Rivers, Chesapeake Bay, Delaware Bay, the lower Hudson, the lower Charles plus Boston Harbor, and the Passamaquoddy—all fall within the latter grouping.

These estuarine bodies occur at many latitudes (and longitudes on east-west oriented coast) in every coastal reach from the northern border of Maine to Brownsville, Tex., and from southern California to the North Slope of Alaska. Hawaii and the far-flung commonwealths and territories contain them also, though island estuaries are usually very small. This extremely wide geographical range has a profound effect on their diversity.

Obviously, with such a range of type, location, and size, estuaries are difficult to generalize about. There are considerable differences in the sizes and slopes of the land areas they drain and in the geometry, hydrography, and biology of their watercourses.

Too, estuaries are subject to varying prevailing atmospheric climates and weather in accordance with their locations, being subjected to widely differing patterns and amounts of rainfall, sunlight, and temperature. See, for example, the maps, zonal concepts and classifications presented in USDI (1969 and 1970), Odum, Copeland, and McMahan (1974), and Clark (1974).

Geophysical features.—Even within themselves estuaries contain different zones or reaches, as for example, a) the upriver, fresh, but tidal reaches occurring immediately below the fall line; b) the intermediate brackish transition reach which connects both oceanic and land-originating waters; and c) the near-oceanic zones at their mouths. Figures 1, 2 and 3 depict various features of a partially-mixed estuary which features partial stratification and two-way surface and bottom non-tidal currents. (To the latter two reaches occurring at the lower ends of tidal tributaries the term estuary is restricted by Pritchard, 1969). Another classification applied to these reaches or zones is oligohaline, or low sea salts (0.5‰–8.0‰), mesohaline, or intermediate sea salts (8.0‰–18.0‰), and polyhaline or high sea salts (18.0‰–30.0‰). Thirty-five parts per thousand is standard full seawater salinity.

Not only are these reaches, extending up and downriver, different but there are marked variations from side to side and from top to bottom involving such characteristics as currents, temperature, oxygen content, transparency, and other aspects. Too, these zones may move horizontally landward or seaward, or vertically toward the surface or the bottom, depending upon regular (seasonal, monthly, or daily) changes in tides or freshwater influx or abnormal winds, coastal surges or land runoff.

Just as morphological and physical aspects of estuaries and coastal waters are immensely complicated and ever-changing so also are their other features. In terms of structural and functional complexity—biologically, chemically and geologically—these waters have no natural peers. They are extremely dynamic and productive.

Biological aspects.—In these chemically rich and fertile estuarine waters and the shallow oceanic areas into which they drain grow most of the marine biological organisms—the plants, marine fish, and shellfish that help nourish many peoples of the world. A large number of authors including Stroud (1971) have concluded likewise.

According to Teal, Jameson and Baden (1972) there were harvested from estuarine and shelf areas 10 billion pounds of commercial finfish and shellfish in 1970. Most of these fish are species which live in (at one time or another in their life stages) or are dependent upon these productive waters. Were the figures utilized by Teal, Jameson and Baden (1972) expanded to include the amounts and kinds of animals and plants taken by recreational fishermen as well as those which are harvested for sale but unreported (undoubtedly a significant number!), the poundage taken would be even more impressive.

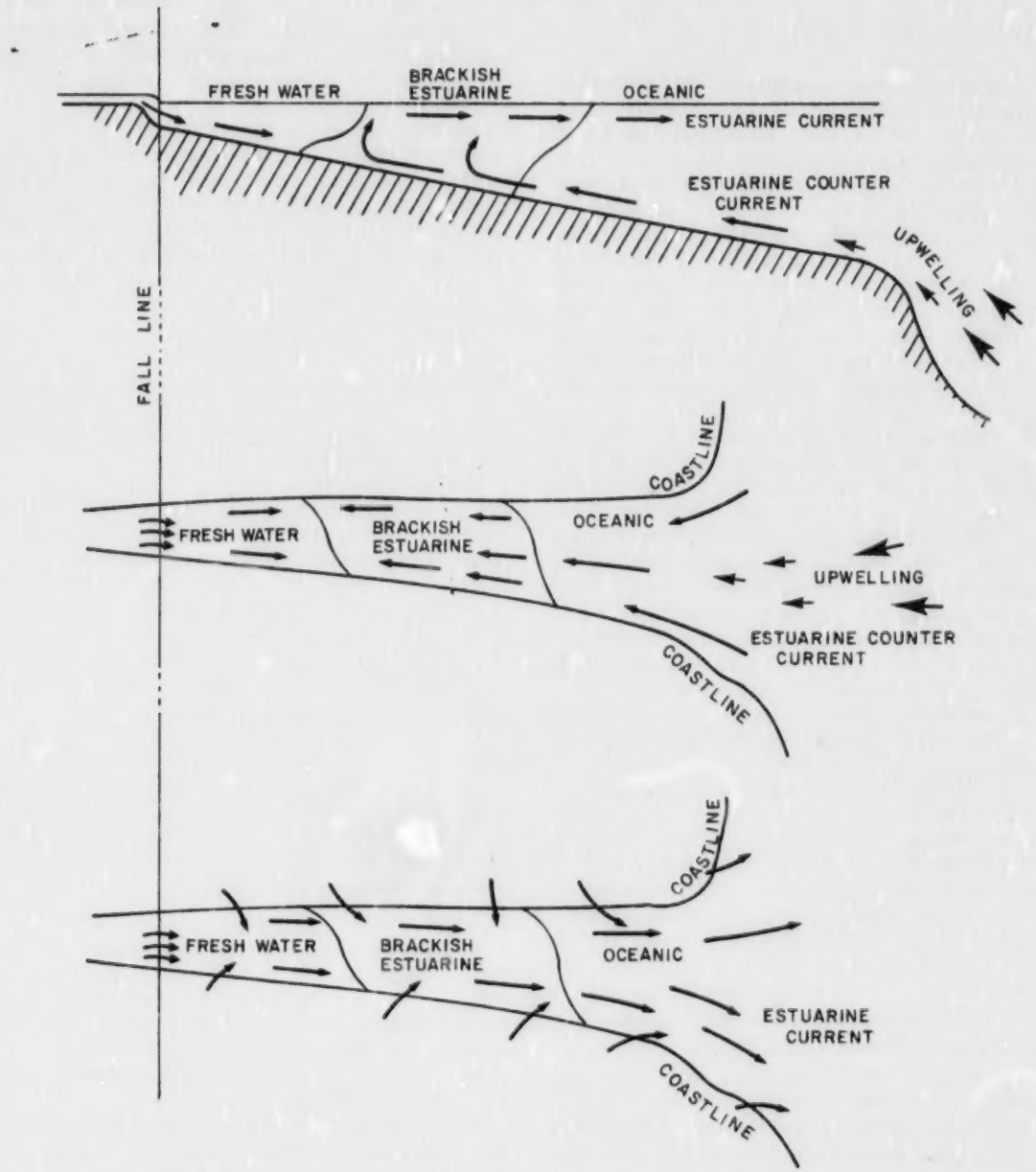

FIGURE 1 (top).—Tidal tributary—profile of mixed type. FIGURE 2 (center).—Tidal tributary—partially mixed bottom circulation. FIGURE 3 (bottom).—Tidal tributary—partially mixed surface circulation.

Of course, these figures do not incorporate the millions of tons of nonharvested animals and plants which grow in the waters of the coastal zone or feed upon their products and which nourish those that are harvested.

Bacteria, countless millions of phytoplankton and zooplankton plants, wetlands grasses, attached and sessile organisms all contribute to this tremendous productivity. In any one estuary thousands of species may occur. Some have extremely complex patterns of

migration and several life stages. For example, the blue crab (*Callinectes sapidus*) has separately identifiable stages and molts several times before reaching its final size. The young stages are planktonic while the adult, an active swimmer as well as walker, lives on or in the bottom most of the time. Their numbers and species composition change from year to year, season to season, day to day, between day and night, and even from hour to hour.

Their physiological activities and dependent environmental requirements are diverse. Some, like the hardy adult *Fundulus* can survive wide ranges of temperature, oxygen, and pollutants. Others are extremely fragile, like the larvae of the Atlantic oyster, *Crassostrea virginica*, which have been found recently by scientists at the Virginia Institute of Marine Science to be very sensitive to chlorine, with an LC_{50} of 0.005 ppm. in 48-hour bioassays. (LC means lethal concentration, referring to that concentration at which 50 percent of the individuals subjected to the substance being tested die within the time specified). Levels well above these (0.02–0.03 ppm) have been observed in the lower James estuary over a mile from the nearest sewage treatment plant outfall. In some species the adults are considerably different in habit, appearance, and resistance. For example, adult Atlantic oysters can tolerate much higher levels and appear to do quite well on beds in the same waters of the James, which contain chlorine concentrations two orders of magnitude above the LC_{50} established for larvae, (Huggett, R. J., personal communication).

Chemical aspects.—Natural chemical constituents of coastal zone waters are derived from land runoff, subsurface terrestrial drainage, interchange with the bottom and with oceanic waters, atmospheric fallout and precipitation, and from biological processes. The actual numbers of inorganic and organic molecules in estuarine (and coastal) waters are great. Even after decades of analysis many molecules remain to be identified; more must yet be properly and fully characterized. As with the biota, the kinds and amounts of chemical constituents vary considerably over time and with various weather conditions. Add the thousands of manmade compounds in varying mixes and concentrations contributed in sewage and industrial effluents and entering from the atmosphere and by land runoff, and an already complex and constantly changing chemical soup is further complicated.

Indeed, their natural complex and dynamic chemical systems are the features which render separation, or detection, and analysis of the various chemical components of these waters so difficult. This bears directly, of course, on difficulties of establishing meaningful baselines, criteria, and standards for many chemical constituents.

Geological aspects.—The geological processes of inshore waters are variable and varied. The amount of suspended matter (hence transparency and color), which includes particles of geological origin as well as microscopic plants and animals (the plankton), varies with, a) fluvial or riverine and lateral runoff, b) winds and currents, and c) biological processes and other hydrographic factors. It also depends upon the condition of the soils of nearby land masses.

High water flows caused by spring rains and thaws and by storms scour the upland river bottoms and adjacent lands. Downstream, estuaries run turbid with the reds or browns of dislodged soil particles. These particles are quite active in picking up and transferring chemicals, bacteria, and viruses from land to water, from water mass to water mass, and from water to bottom sediments and back again. In this way beneficial chemicals, i.e. necessary nutrients and trace elements, are brought into the system. Unfortunately, toxic molecules and microbes are also.

While dancing about in estuarine waters, suspended silt acts to "scrub" the water and to enrich it by releasing nutrients. Pollutants carried to the bottom by falling silt and stored in the sediments later may be recycled during periods of high turbulence induced by winds or currents. They can also be recycled and relocated by dredging and spoil disposal operations. Too, processes of erosion, transport, and deposition move geological materials up and down the estuary and from shallower to deeper waters (and vice versa where conditions are right). Estuarine sediments are carried on outgoing tides and currents into the waters of the open coast and the reverse may be true.

Eolian earth particles, generally with attached (or accompanied by) chemicals and plant and animal matter are deposited in estuaries. Fallout and precipitation also inject natural and unnatural atmospheric travelers. Some, like lead and its derivatives and radioactive particles, can be troublesome.

The biology and chemistry of shallow waters of the sea are closely dependent upon the geological activities mentioned above. Since these waters and their processes are all complex and varying, the resultant "broth" is likewise, contributing further to difficulties of understanding, definition, and control. Thus, they present great and growing problems to scientists, engineers, and management people alike. Great, because of the natural complexity and their dynamic

nature. Growing because of the added contributions and pressures of burgeoning coastal populations.

FEATURES OF COASTAL WATERS

Outside of the mouths of the great bays and tidal tributaries and of the passes and inlets of the fringing bays, lagoons, and sounds lie the coastal waters. Shallow and turbulent, yet bordering on the depths of the oceans, these coastal waters are subject to effects of wind and of water injected into them from upland drainage and from the wetlands, estuaries, bays, and sounds they drain.

In the deeper passes and rivers and through the bay mouths a two-way flow exists with saltier shelf water flowing inward at the bottom while fresher and lighter estuarine water flows outward at the top. In some this flow pattern is reversed. In yet others the lighter, fresher water flows out at one side and the saltier, heavier water in at the other. Thus, coastal waters receive fresher estuarine and surface runoff waters (or saltier water from hypersaline embayments) as well as contribute directly to estuarine flows. Additionally, inshore coastal waters may be augmented by upwelling from deeper oceanic basins, by water masses moving alongshore, and by injections and meanders from powerful ocean currents like the Gulf Stream. As shown schematically in Figures 1, 2, and 3, all receive surface drainage and lateral flowage into their surface waters, to say nothing of injections from the atmosphere via precipitation.

In these coastal waters mixing is usually vigorous and large volumes of water are available; hence, quality as determined by dissolved oxygen is generally good. However, domestic and industrial outfalls dominate in some places. Where they do, quality is often poor. There are some locations, too, where circulation patterns may concentrate pollutants or flotsam and jetsam, which remain either offshore or move toward and onto shore. These places are usually unsightly or foul, or both. There are reaches of beaches where wave energy is focused into such strongly erosive forces that surface and subsurface structures are endangered by buffeting and erosion. (Goldsmith, V. G., personal communication). Obviously, such features would have to be considered when placing, building, and operating ocean sewage outfalls or in disposal of dredge spoils, sludge, trash, or other materials.

Semi-estuarine situations.—At places along the coast peninsulas and promontories may so restrict circulation as to produce semi-lagoonal or semi-estuarine situations. In such cases, assimilative and dispersive capacity may be restricted or reduced and the system may behave like an estuary or lagoon. Sewage outfalls and sludge deposits should not be placed in such coastal reaches unless slow dispersion or containment is desired.

People—Another Estuarine Concept

Coastal waters and/or estuaries have been established above as complex and dynamic natural systems in their own right. Neglected has been mention of people, people in concert—of society and its impacts on these difficult and fragile ecosystems.

THE EFFECTS OF MAN

As we have seen, even without society and its varying needs and wants and its changing demands and pressures, estuaries and coastal systems are sufficiently complex and dynamic to confuse comprehension and confound management. Add man and his works and the difficulties of understanding, working with, or managing them are magnified and compounded.

Society's demands.—Society has been living on the shores of the seas since before written history and long before the problem of waste management became a major concern. Society's demands on the environments and resources of the estuaries have grown and changed over the millennia as they are doing even today. Beginning with simple wants and needs, the demands of the small populations comprising early families and tribes and tribal confederations probably worked no significant hardship on estuaries. However, as engineering capabilities have developed and human populations and maritime industries have grown and changed, man's impact on the estuaries has magnified also. It is sufficient to point out here that the impacts of society on estuaries and coastal waters have increased markedly in size, number, and complexity and that they are dynamic, changing as society's needs, demands, and technological abilities do.

Man's activities, too, can only be roughly categorized and understood, at least partially, but their dynamic effects introduce a whole new dimension of difficulty into our attempts to understand the ecosystems involved. With man in the picture, estuarine and coastal ecosystems become increasingly difficult to understand.

Growth—one factor.—That most of the people in the United States live on the shores of the oceans and their tidal tributaries or of the Great Lakes has been stated and demonstrated many times. Further repetition is unnecessary. Sometimes neglected, however, is the fact that each year the populations of the coastal counties of the nation change in numbers, generally increasing ("The National Estuarine Pollution Study," USDI, 1969). Too, the specific demands placed on estuarine ecological systems vary from region to region, from estuary to estuary, or even within estuaries.

Time—the other factor.—One other natural factor plays a role in both coastal waters and society, that of long-term, one-way and normally irreversible change—evolutionary change. As do natural, undisturbed estuaries, societies undergo evolutionary changes as well as short-term modifications. Those alterations wrought by nature usually require longer periods of time, while those of man often require only a short time. Man-caused modifications are taking place at an increasing rate and are of growing magnitude as technological skills permit.

Long and short-term changes.—Superposition of the short-term, dynamic characteristics of estuaries and coastal waters with their daily, seasonal, and other cyclical changes upon the slower, largely unidirectional alterations of nature makes understanding and control difficult. Adding the alterations of man and his changing numbers, needs, and uses compounds this dynamism. In truth, estuarine and coastal ecosystems with their added burden of society are not only complex and sometimes fragile but they are variable and varying. Thus, even without man they are difficult to study, to learn, and to know. Add society and these difficulties are worsened. Man can make substantial changes even while conducting studies designed to learn how things were! These changes can so alter the nature of the system as to make new studies necessary, even before the old one is completed!

How can estuaries and coastal waters be understood?—There are certain basic similarities among the myriad and unique estuaries and coastal waters, to be sure. Similarities of structure and function, which can be used to develop understanding, principles, and models can be detected and described. By doing so, common factors of the classes, systems, and phenomena of estuaries and coastal waters can be ascertained and generalized frameworks for management, use, and preservation developed. But prescription of uses or the most economical and reasonable basis to meet the needs of nature and society can only be accomplished by a detailed local knowledge of each estuary or inshore zone and of each of its affected operational segments.

The Receiving Streams

Having established that coastal waters and estuaries are complex, dynamic, variable in location, extent, depth, and in other critical dimensions and that they are subjected to varying conditions of tides and climate and other features, it remains to establish clearly why these features are important to our purposes. It is because these are the receiving streams, the waters for the effluvia and rejecta of coastal societies (and even those far inland). And it is their absorbing, diluting, and modifying powers which, coupled with the contaminants and alterations of man, will determine the ultimate questions of quality within coastal zone waters or even far at sea—of whether or not pollution exists and its extent.

UNDERSTANDING FOR MANAGEMENT

These waters, therefore, must be understood and that understanding must be utilized in any sound program of water quality (or wastewater) management. Obviously, all of the factors mentioned above, natural and social, must be known and considered when water quality criteria are being developed, when standards are established, when control and monitoring schemes are projected, and when projects for industrial development, recreational development, utilities, housing, and other activities are being planned, sited, constructed, and operated.

The biological, chemical, geological, and physical characteristics of estuaries and coastal waters and the realities of social activity on the coasts will ultimately determine not only the nature of the uses to which these environments can be put without severe damage to them and to society but also determine the costs.

Economics also must be considered. Under current conditions of world wide economic stress it is apparent that every effort must be made to maximize the productive uses to which marine resources and environments can be put while retaining their utility, viability, and potential. The food, minerals, recreational, and aesthetic aspects and the cooling and absorptive properties of estuarine and coastal waters are of great economic value!

Variation and environmental management.—Thus, estuaries, which in reality are complexes of natural ecosystems and ecotones (smaller zones of transition between ecosystems), are extremely varied and variable. Because of their variety and changeability and their wide variation in size and location, estuaries are hard to generalize about, to know, or to deal with as a group or in classes. They are almost as variable and difficult as human individuals and present similar difficulties to students and managers alike. Groupings can be made, but in the last analysis they must be understood and managed as individuals. Doing so poses massive problems and great strain, and requires considerable knowledge, care, and skill. Careful environmental and resource engineering is required. Management must be sophisticated and well-equipped with technological capability. It must also be well-staffed and provided with scientific knowledge of the environments and resources involved and of society's needs and demands. A close interaction between management and science and engineering is required. Unfortunately, at present there are many shortcomings in the ability of each to respond to the problems. Not the least of these is a lack of understanding of the complex and dynamic environments and resources which we seek to utilize wisely or of the "real" present and future needs of society.

WATER QUALITY ASPECTS

It is not within the province of this essay to comment in detail upon possible organizational arrangements for management or for all of the myriad scientific and engineering activities required to determine how much of man and his various demands the environments can tolerate and support. Instead, it is our task to evaluate trends in the quality of estuarine and coastal waters, to examine existing water quality criteria, and to evaluate the state of the art in establishing and evaluating water quality and water quality criteria.

Quality of Estuaries and Coastal Waters

Many authors and groups have examined and commented on quality of marine waters in the last two decades. Their pronouncements range from doomsday statements (such as the public pronouncements made by irresponsible, unfettered environmentalists) to euphoric, optimistic ones (such as those propounded by some industry spokesmen or development-oriented propagandists). As frequently happens, the truth seems to lie somewhere between the two extremes. However, there can be little question that man and his demands are pressing the resources and environments of the coastal margins of the World Ocean—and heavily.

CLASSIFICATION AND QUALITY

Findings of "The National Estuarine Pollution Study."—This work (USDI, 1969) divided coastlines, the United States, and its commonwealths and territories into the 10 biophysical regions depicted in Figure 4. It then proceeded to typify the classes of estuarine and coastal waters within each region and to discuss their condition.

It would be profitable to examine anew and in detail the conditions of uses, modification, and the quality in each of these 10 zones and to conduct a thorough review of all estuaries and coastal waters included; however, restrictions of time and space do not allow it. Fortunately, we can utilize previous work.

"The National Estuarine Pollution Study" did find that 25 estuarine systems (page II 60), including Penobscot Bay, Boston Harbor, New York Harbor, Raritan Bay, the Delaware Estuary, Baltimore Harbor, the upper Potomac, the James, Charleston Harbor, San Juan Harbor (P.R.), Tampa Bay, the lower Mississippi Laguna Madre, San Diego Bay, Puget Sound, Silver Bay (Alaska), and Hilo Harbor (Hawaii) "show definite documented water quality degradation as a result of human activities." It further stated that for "38 percent of the systems of the United States there is a lack of information to allow judgment of whether there is ecological damage, or whether there are just no easily identifiable problems present"—yet.

The report proceeds to point out that, "Wherever people live, work and play in the estuarine zone the demands of their social and economic activities place stresses on the biophysical environments. These stresses frequently result in degradation of that environment, perhaps not immediately or even in a few years, but nonetheless certain in its devasting final impact."

The study continued (Page II 61) "The complex nature of pollution in the estuarine zone (Author's note—used broadly in that study to include all tidal coastal waters as is done herein) prevents the separation of sources of pollution, kinds of pollution and types of environmental damage into neat compartments of cause and effect. All of human activities in the estuarine zone can damage the environment and most of them do." The report imparts a decidedly negative impression of the condition of the Nation's estuaries.

FIGURE 4.—Biophysical regions of the United States (from The National Estuarine Pollution Study, U.S.D.I., 1969).

Whether one subscribes to this somewhat dismal and dismaying conclusion, there is no question that for each use to which man puts these waters there is a cost in quality or quantity or both. The objective of good management is to arrange it so that our uses and demands absorb only what nature can spare—that we use only the overage or excess, the interest and not the principle. We must be "good" parasites and not kill the host.

Findings of "The National Estuary Study".—After developing a series of interesting color-coded maps depicting the condition of estuaries and coastal waters according to whether they were: 1) relatively unmodified, 2) moderately modified, or 3) severely modified, this effort (USDI, 1970) presented a table illustrating the degree of modification of estuaries. Like the chart previously mentioned (Figure 4) this table (adapted for use herein as Table 1), utilized biogeographic zones. Of all of the American estuaries and subestuaries reviewed, 23 percent were severely modified and 50 percent were moderately modified while only 27 percent were slightly changed. Thus, in the opinion of the preparers of that study, a large majority (73 percent) of the estuaries and subestuaries in the United States had been moderately or severely modified by man. Even though some of the modification described is in the form of summer-home encroachment on scenic areas (an activity whose damaging impacts are often difficult to establish or qualify), this is a staggering percentage considering the fragility of estuaries and their importance to the adjacent seas and to the economic and social welfare of man. Much of the modification recorded by this study, directly relates to the problem at hand—degradation of water quality by pollution and modification.

Good is not good enough!—It is possible to find weaknesses in both studies and in all other such nationwide, general evaluations. It is easy to point out that some of these systems are naturally "dirty;" that they were on the evolutionary road to oblivion long before the industrial and technological revolutions began and the population pressures of today developed. We can even point with pride at the efforts being made to eliminate or reduce toxicants, nutrients, and harmful changes—and we should!

Table 1.—Modifications of the Nation's estuaries.[1] Most estuarine areas of the United States have been modified more or less severely by man's activities. The degree of modification is indicated by regional zones in the following table:

Biogeographic Zone	Degree of Modification of Estuaries[2]		
	Slight	Moderate	Severe
	Percent		
North Atlantic	44	48	8
Middle Atlantic	5	68	27
Chesapeake Bay	44	50	6
South Atlantic	36	60	4
Biscayne and Florida Bay	50	50	0
Gulf of Mexico	15	51	34
S.W. Pacific	19	19	62
N.W. Pacific	13	50	37
Alaska	80	20	0
Hawaii	54	15	31
Great Lakes	35	46	19
United States	27	50	23

Source: Field evaluation carried out by Fish and Wildlife Service's personnel during course of Estuary Protection Act study.

[1] From the "National Estuary Study" (U.S.D.I., 1970)

[2] All estuaries and subestuaries were individually rated for each zone. The percentage refers to the proportion of these individual areas that were rated as indicated.

The condition of some estuarine areas has been improved or the rate of degradation altered, as for example the upper tidal Potomac, New York Harbor, and San Francisco Bay. There must remain, nonetheless, the conclusion that the best that we have done or can do under present conditions of knowledge, technology, and commitment is not enough. All of the signs available today indicate that the quality of estuaries and coastal waters continues to decline. We are making 3 knots against a 4 knot current. Our water quality management effort is making "sternway"—more slowly than without the effort, but sternway nevertheless. We are still losing!

It is to be expected that the current economic downturn and the lowering trend in population growth will slow the rate of degradation or modification of estuarine and coastal environments and resources but it is doubtful that progressive degradation will be stopped until knowledge and control techniques and arrangements improve markedly. Pressures of the coastal zone continue to grow as the population of the United States rises (by births, decreasing mortalities, and immigration) and especially as the populations of the counties, cities, and towns in the coastal zone grow due to the continuing coastward movement of people. We have not yet learned how to establish carrying capacity of specific land areas or river basins or how to control population levels in specific regions. We must! Indeed, there is as yet no general agreement that in some places or at certain rates and levels, growth becomes a problem, one which must be directly attacked and solved. We talk of food and resource shortages and environmental problems, but never seem willing to face its root causes—too many people, too many demands. We seem to have a blind side when it comes to population and to growth. We still generally seem to believe the more the better, even if not the merrier. This abysmal attitude is discouraging.

It is not possible to agree, however, with the doomsayers that the oceans must die in a decade or three or even five decades. Nor is it possible to agree with those who apparently believe that man has no right to occupy the coastal zone or to use or modify its resources and environments. Both conclusions seem overdrawn. The last is foolish! Man, too, is a product of nature, of the evolutionary process, and belongs naturally on planet earth. It is necessary to conclude, however, that the quality of the coastal zone is being degraded and that we have neither learned to appreciate and apply the well established concepts of carrying-capacity, nor how to match ourselves with nature—nor to understand and manage either well. Much must yet be learned!

Existing Water Quality Criteria

The conclusion that the United States continues to lose ground in its fight to reverse the trend of degradation of estuaries and of coastal water does not detract from the positive efforts that have been made at the federal level, by Congress and the Executive, by state legislative and executive authorities, and even by many regional and local bodies. Fruitful efforts to improve management capabilities have gone forward under the several acts mentioned above. Most states, counties, and cities have increased their efforts at controlling pollution and engineering and there has been general improvement. As pointed out above, some estuarine areas have been partially cleaned up. In others, the progress of degradation continues with little abatement.

Among the efforts that have contributed positively to our increasing control over the factors affecting water quality have been the Water Quality Criteria developed by the National Technical Advisory Committee (NTAC, 1968) and the several panels of the Water Quality Committee of the Environmental Studies Board of the National Academy of Sciences-National Academy of Engineering (NAS-NAE, 1973).

The Environmental Protection Agency has also recently developed suggested criteria (EPA, 1974). These will be considered in order.

THE NATIONAL TECHNICAL ADVISORY COMMITTEE

Based upon a review of published data and conclusions, and including even unpublished data, a group of scientists and engineers familiar with the various problem areas was gathered, to accumulate, evaluate, and summarize a wide range of the existing knowledge related to water quality with the purpose of establishing water quality criteria and recommendations for management. The results of their considerable effort were published in 1968 and the report quickly became known as "The Green Book" (NTAC, 1968a). Of course, the NTAC owed much to earlier encyclopedic efforts such as those by Vinogradov (1953), McKee and Wolf (1963), and to many technical papers produced by previous workers.

The Results.—In addition to addressing the water quality requirements for the various broad categories of uses to which natural waters are put, or for the aquatic resources on which the various uses may be based, the Advisory Committee considered certain details of the many pertinent sampling and analytical procedures.

Within these categories of uses and the resources on which those uses depend, many species of chemicals and groups of manmade contaminants were considered. These included toxic or damaging chemicals, oils, and heavy metals, as well as other factors, for example, nutrients, turbidity producers, and color modifiers.

Summaries of the demands and requirements for water by various major industrial activities considered were also provided in "The Green Book."

Specific criteria and standards.—Specific criteria or recommendations for management of quality were developed where possible. Unfortunately, the water quality criteria established by NTAC were too quickly converted by the authorities responsible into "Standards." The word "unfortunate" is used because in the rush to develop those standards the caveats so clearly specified by the committee in preparing the report, were ignored. They were restated by J. G. Moore, commissioner of FWPCA, in his letter of transmittal to then Secretary Stewart L. Udall; Moore pointed out that "Regional variations in climate, typography, hydrology, geology, and other factors must be considered in applying the criteria offered by the Committee to the establishment of water quality standards in specific localities" (NTAC, 1968a). However, the criteria were transmitted quickly into standards of control for wide geographic application. Several other cautionary notes or warnings included in the report were apparently unheeded. As a result, many of the standards prescribed are impossible of attainment.

Mixing zones and zones of passage.—Too, the Committee addressed itself to other problems related to management of water quality in estuaries and coastal waters such as "mixing zones" and "zones of passage." These two subjects are quite important since as long as there are effluents to be released there will be mixing zones and the problem will be to keep them limited in extent and number to the bare minimum required.

Limitation of mixing zones is necessary to allow multiple use of the waterways in question and survival of the fish, wildlife, and other species of the normal biota so vital to the economic and aesthetic activities of man. Additionally, effluent mixing zones must be so arranged within an estuary (or along the coast) as to allow adequate zones of passage for species which must travel (or be transported) up and down stream or along shore, such as herring and shad, striped bass, and most other coastal and/or estuarine-dependent fishes. Pelagic larvae of oysters and clams and a host of other ecologically or economically important shellfish are also involved.

Research Needs for Water Quality.—In addition to the water quality effort, the National Technical Advisory Committee also reviewed the research needs related to establishing and improving water quality criteria and standards and for monitoring natural and modified aquatic systems. Its report, "Research Needs" (NTAC, 1968b) was published after "The Green Book" appeared. Unfortunately, its recommendations have not been well-heeded and much of the important research and development activities urged in that report has not yet been accomplished.

THE NAS-NAE ENVIRONMENTAL STUDIES BOARD

The efforts of the various panels of the Environmental Studies Board of the National Academy of Sciences-National Academy of Engineering seem to have been patterned after the work of the NTAC. This activity, conducted under a contract from the Environmental Protection Agency, resulted in a voluminous report which is, not surprisingly, coming to be called "The Blue Book" because of its

striking blue cover. The report utilizes the same broad categories of water uses and water-dependent resources (aquatic life and wildlife) as did the NTAC effort. Too, the NAS-NAE report makes recommendations for management guidelines and criteria for the various classes of contaminants and the important chemical molecules known or believed to be of importance in water quality.

Improvements over earlier efforts.—"The Blue Book" effort of NAS–NAE included far more data in its presentation, than did that of the NTAC. Of course, the NAS-NAE panels had the benefit of several more years of research but they also seem to have been able to encompass more of the available data than the 1968 study did. Review of the report in preparation of this article, confirms the statements of Drs. Handler and Linde, presidents of the National Academy of Sciences and the National Academy of Engineering respectively, which said, "The 1972 report drew significantly on its 1968 predecessor; nevertheless the current study represents a complete reexamination of the problems, and a critical review of all the data included here."

Shortcomings.—While generally a significant improvement upon the earlier NTAC work, the 1972 report has some shortcomings. For example, "The Blue Book" fails to address the possible water degrading effects of modifications of the various geophysical parameters, such as: a) bottom topography, depth, and shoreline contours by dredging and spoil disposal; b) shoreline contours and basin cross-section by shoreline filling or cutting; c) current modifications as by training wiers; and d) inflow changes as by impoundments and diversions of upstream waters. As the NTAC study pointed out in "The Green Book," these modifications may have profound effects on such important factors as circulation patterns, tidal patterns, and salinity levels, among others. The significance of modifications in the natural order of things caused by these activities, both by themselves and in concert with introduced contaminants, has been treated by a number of authors. (See for example the works of Hargis, 1966 and 1972; Chapman, 1971, and others, as well as the appropriate sections of the NTAC report).

These aspects have also been ignored in the development of many of the various water quality standards by the states and EPA. Perhaps this is because many state water quality management organizations do not have primary jurisdiction over channel dredging or water diversions or similar engineering-type projects. Nonetheless, a salinity or current change induced by the deepening of an estuarine channel or by diversion of freshwater inflow can have as far-reaching effects on water quality, on fishery and wildlife resources, and on users as any chronic contaminant.

A basis for revised criteria and standards.—Despite these criticisms (and there likely could be others) "The Blue Book" should provide a broader and firmer basis for specific improvements upon the criteria and standards developed in earlier efforts. It will be necessary for the standards-setting agencies such as EPA and state governments to consider well the qualification stated in the general introduction, to wit: "The Committee wishes to emphasize the caveat so clearly stated in the introduction to "The Green Book." The Committee does not want to be dogmatic in making its recommendations. They are meant as guidelines only, to be used in conjunction with a thorough knowledge of local conditions." In other words, the Committee can be interpreted as saying that these recommendations and criteria should not, indeed cannot be, automatically adopted as nationwide, regional, or even statewide standards.

EPA's Proposed Criteria for Water Quality

Following the work of the NAS-NAE Committee on Water Quality, EPA prepared its own report ("Proposed Criteria for Water Quality," Volume I and "Water Quality Information," Volume 11, 1973) in partial fulfillment of the provisions of Section 304(a) of the Federal Water Pollution Control Act Amendments of 1972. According to Volume 1, page 12:

> Water quality criteria as compiled in this document are defined as the acceptable limits of constituents in receiving waters based upon an evaluation of the latest scientific information by the Environmental Protection Agency. They are to form the datum for the Agency's 1983 interim goal of improving the Nation's waters to a quality that provides for the protection and propagation of fish and wildlife, and for the health of humans in their pursuit of recreation in and on these waters.

An EPA Comparison of Criteria

The EPA Document, "Comparison NTAC, NAS and Proposed EPA Numerical Criteria for Water Quality" (EPA No. 449, no date, probably 1974) comprises a comprehensive tabular comparison of those criteria which can be presented in numerical form or as brief narratives. It is based upon all

three documents mentioned above, i.e. the NTAC "Green Book," the NAS-NAE "Blue Book" and EPA's "Proposed Criteria for Water Quality" and is useful in drawing a great deal of data together, allowing a quick comparison.

In general, a review of these new EPA documents indicates that the current proposed EPA criteria are based closely upon those presented in "The Blue Book." This seems an acceptable procedure since the NAS-NAE effort is the most recent and complete compendium currently available, as far as this author is aware.

Missing parameters.—Unfortunately, several of the significant chemical parameters such as nitrates, nitrites, phosphorous, salinity, and others, are not indicated in the EPA Criteria even though one or the other (or both) of the two basic compendia of criteria (NTAC, 1968a and NAS-NAE, 1972) did think them sufficiently important to examine and mention. This lack should not deter states, or EPA for that matter, from addressing these ecologically and economically important features.

Development of Standards

The purpose of criteria is to provide a basis for development of standards and management procedures. However, the cautions expressed above regarding the universal applicability of any of the previously developed criteria for adoption or modification as standards must be considered. Standards developed directly from criteria without due care of their limitations for use in specific locations or situations cannot, indeed will not, be adequate. The ills of estuaries and coastal waters, like human health, must be managed on an individual basis. Too, as will be seen, many of the data currently available and used in developing criteria and standards are not especially well-verified nor is their significance known. In many instances sufficient data are lacking. All of these factors present very real limitations upon criteria and upon standards developed from them and future revisions in both will be necessary. Like many current medical data and practices, however, they are the best we have to work with, and the patients (the marine waters in this case) have problems and must be treated now!

The State of the Art: An Examination

Having concluded that the water quality criteria developed by the three groups mentioned above are probably the best that could have been achieved by any reasonable national effort, examination of the foundations on which they are based is necessary. To develop the most effective and least costly management effort possible requires, among other things, standards that reflect reality as accurately as possible. Poorly founded standards place unnecessary burdens on the user and his customers, if any, (if too high) and on the public's environments and resources (if too low). Like other types of engineering, environmental engineering must be based on reliable or "real" data and it must be done to as close tolerances as possible!

All three of the groups involved with developing national criteria had to deal with certain difficulties, though NAS-NAE and EPA had fewer to handle than did the NTAC—the pioneer group. Each was faced with formidable tasks of attempting to accumulate and evaluate data from many sources within restrictive periods of time. The NTAC effort probably suffered most in this last respect; its working life was limited to a few months.

Adequacy of Basic Data

The data that are available are variable in statistical and analytical reliability. Frequently, it is difficult to validate them, even with adequate time. Under pressing time constraints a great deal must be taken on the reputation of the author or institution performing the work—or on pure faith!

Status of scientific knowledge.—Actually, the coverage by science of the various chemical, physical, and biological parameters involved in water quality is variable. Some have been well investigated—some only superficially. Fortunately, the coverage and the competence of that coverage has increased rapidly in the last decade, but serious gaps remain.

Analytical weaknesses.—It is extremely difficult to detect many of the possible harmful chemical constituents in estuarine and coastal waters because these waters contain so many natural chemical substances. As the analytical chemists aver so colorfully, these waters are extremely "dirty." Often, the contaminants involved are effective or toxic in extremely minute quantities, (i.e. tenths or hundredths of parts per million or even tenths or hundredths of parts per billion). Too, they are frequently so similar to natural constituents of tidal waters that they are difficult to separate analytically. Also, they may appear, do their damage, and be removed by

natural processes of sedimentation, flocculation, circulation, or dilution. Because of these problems effective analyses are difficult.

For some chemicals, techniques of detection are still poor. In other words, analytical methods are weak or they are cumbersome—requiring specialized equipment or skills. For many chemical constituents, only especially well-staffed and equipped laboratories are competent. All too frequently, enforcement laboratories are neither. The same may be said of some institutions engaged in basic research involved in generating the data which are later incorporated into reports such as those under discussion.

Standardization weaknesses.—Standardization of sampling, analysis, and reporting is weak. It is, therefore, difficult to compare results or evaluate them. In addition to all of these negative factors, instrumentation and other facilities for sampling in the field and laboratory, are in many instances, poor or nonexistent. An excellent example is the lack of readily available reliable and rapid analytical techniques for detection of chlorine and chlorine by-products in estuarine waters. Standard chemical techniques are poor and instrumentation weak. Only in the last year has there been a promising breakthrough in this area due to joint efforts of the National Bureau of Standards and the Virginia Institute of Marine Science (R. J. Huggett, personal communication).

To the all-too-frequent incompetence of specific sampling and analytical groups must be added the extreme variability and dynamic nature of the estuarine and coastal waters, themselves. These aspects were discussed in detail above.

Sampling and experimental difficulties.—Estuarine and marine animals and plants are difficult to sample effectively in nature. Statistically significant samples are hard to secure. Laboratory experimentation is even more difficult since the organisms involved often have complex life cycles with several stages, some of completely different habits. It was pointed out earlier that adult oysters are sedentary but the spawn of many species are discharged into the water. Many of the larvae are free-swimming. The larval, free-swimming stages are more susceptible to adverse water conditions than are their sessile parents.

Few marine species have been effectively held in the laboratory even for one life stage, much less for a complete life cycle. Far fewer have been reared or cultured under controlled conditions. Laboratory lines of known genetic makeup and environmental history (as for example in the mice or rat populations so dear to the hearts of medical experimenters) are almost unknown. Unfortunately, little effective sustained effort to overcome these weaknesses is in progress.

Weaknesses in bioassay data.—Many of the estuarine and marine criteria adopted by NAC and NAS-NAE are based upon bioassays conducted on freshwater species alone. Often those done with actual marine and estuarine species have utilized only the most hardy, the most difficult to damage or kill. It is desirable, as EPA workers have said (EPA, 1973), to base criteria and standards on the most important (importance is defined in several ways, i.e. in numbers, economic importance, position in food chains and others) species in the estuarine or coastal system for which they are being developed. This is an objective rarely attained! As a consequence, criteria and standards are often based upon extrapolations from less important and tougher species.

The uncertainties devolving from these shortcomings render certain of the current criteria and standards of dubious validity or significance. Too, the safety factors involved in extrapolation to account for and cover the basic weaknesses in the data are extremely high, often placing severe economic burdens upon the users who must engineer to meet the standards.

Criteria for certain biological contaminants.—The above described difficulties occur in many of the chemical analyses (organic and inorganic), environmental observations, and bioassays utilized in management of estuarine and coastal waters. But nowhere is the data base as weak as those on which the criteria and standards for pathogens, fungi, bacteria, and viruses, must be founded. There are many basic unknowns concerning the viability of viruses in natural waters. This is especially true of viruses in estuarine and coastal waters (Vaughn, 1974). The same applies, but to a lesser extent for bacteria where the significance of the basic examinations, measurements, and standards have been in question for almost 20 years. Despite its human health significance and importance to quality control, this aspect of water quality has been badly neglected. The criteria and standards suffer accordingly. Much additional work is required. Unfortunately, few research laboratories are equipped or staffed for (or concerned over) observations and experiments in this area. Apparently, many local, state and federal water quality laboratories are weak also. The number of competent microbiologists and

microbiological technicians with experience working with estuarine and coastal waters is believed to be small.

This lack of interest and broad capability with such important health-related factors is especially troublesome. Unfortunately, no good techniques for sterilization or removal of viable viruses from effluent waters now exist (Vaughn, 1974).

There are many other areas of weakness in basic understanding of the factors important to effective water quality management.

BASELINES

Given the complex and dynamic nature of the waters under consideration and the vast volumes and areas involved, it is little wonder that baseline knowledge, or understanding of the natural ambient conditions, is not strong. Until recent years effort in the field and laboratory has been spare and weak. To be sure, conditions have improved in the last decade-and-a-half, but holes in the data remain. A number of the estuaries and coastal waters of the United States have been investigated, but many have not. As an example of the magnitude of the task involved, the Chesapeake Bay has been the home and arena of activity for what has been probably the largest aggregation of estuarine scientists in the world since before 1950, yet much remains to be done. As an example, among the several institutions involved have been the Chesapeake Biological Laboratory at Solomons, Md., and a part of the University of Maryland; the Chesapeake Bay Institute of The Johns Hopkins University in Baltimore, Md., the Virginia Institute of Marine Science at Gloucester Point, Va.; the National Marine Fisheries Service Laboratory at Oxford, Md.; the Environmental Protection Laboratory at Annapolis, Md., Old Dominion University in Norfolk, Va.; the Westinghouse group at Annapolis; and the several state investigative units in both Maryland and Virginia. Other institutions and individuals have been active.

CONCLUSIONS CONCERNING PRESENT CRITERIA AND STANDARDS

Clearly there must be shortcomings in existing criteria and standards since they are based, in part, upon the current, somewhat inadequate baseline knowledge of a) the environments involved and b) the requirements and tolerances of those environments and of the animals and plants living therein or dependent thereupon. For some parameters, these shortcomings such as uncertainties over the fate and significance of petroleum hydrocarbons, halides, heavy metals, viruses, and bacteria are serious! Others are understood better.

Standards and local knowledge.—Standards should be based on competent local knowledge using the nationally developed criteria as a guide. In most instances, the level of knowledge required is very high and quite detailed for a specific localized environment. Frequently, information does not exist or is weak. Most often, data have been hastily gathered, covering only a short span of time. Given the nature of biological cycles and the seasonal and annual variability of precipitation over estuarine and coastal systems (and the extreme perturbations (i.e. wet or dry) and other extreme weather phenomena) many of the observations now available for use in design and operation of industrial plants and sewage outfalls are weak. Inasmuch as this ignorance introduces uncertainties into the criteria, standards, and permit systems that obtain, and since engineering to cover those uncertainties requires much effort and cost, if one must overdesign and overconstruct, adequate baseline knowledge is important! Examination of the current situation indicates that much additional effort directed toward improving our baseline knowledge is required.

Monitoring

Even after water quality criteria and standards have been developed and programs for construction and operation of treatment plants are under consideration—or actually in being—more remains to be done. Public and private managers must track and learn the amounts and characteristics of discharges and they must determine the condition of the environment and biota on a frequent, even continuous basis. Monitoring capability is required! Without it it is impossible to evaluate success or failure of the management program, to establish blame, or to rectify problems.

Monitoring requirements.—For monitoring to be effective, it must be timely, accurate, precise, and complete in coverage. For many parameters it must also be frequent and regular. Its reliability should be assured.

Monitoring limitations.—Unfortunately for management, the same factors which made baseline development and bioassay difficult also plague monitoring efforts. In situ monitoring instruments of

reliable quality are not readily available at reasonable cost even now. Analytical techniques are inadequate and adequately trained technicians are sparse. The salaries of water-treatment technicians are frequently too low to attract people of the required level of training and reliability. Management of treatment facilities is often weak.

All too frequently public water quality control agencies are forced to rely on effluent data gathered and supplied by the discharger. Properly controlled, this obvious shortcoming need not be too damaging but often there is no adequate followup or check. Without adequate checking such self-monitoring by dischargers must always be suspect. Many treatment plants are plagued by chronic overloads, poor management, and inept personnel. Breakdowns in equipment and procedures are frequent and the "midnight valve" appears to be the ready resort of operators with troubles.

It is not unusual that the public agency whose task it is to provide management-level surveillance or monitoring of effluents in estuarine and coastal waters, is poorly prepared to do so. These weaknesses are unfortunate because:

> The effectiveness of water management programs depends in major part on the scope, accuracy, and precision of the characterization of both the waste sources and the receiving waters. Rational waste control systems and facilities cannot be developed and operated without accurate information on the significant sources of waste, and on their relation to the receiving water characteristics established for protecting the beneficial uses. Only in the light of this type of information can the limited financial resources available for waste control measures be effectively allocated.

The preceeding quotation is the paragraph that introduced the excellent chapter dealing with monitoring included in the NAS-NRC (1970) study entitled "Waste Management Concepts for the Coastal Zone." The reader is referred to that document for a more comprehensive treatment of the problem.

The NAS-NRC Committee examined the needs of monitoring carefully and in detail. Others have recently addressed the problems of monitoring marine pollution at a workshop sponsored by the National Oceanic and Atmospheric Administration in southern California (Goldberg, ed., 1972a). Their results confirm the opinions expressed above.

A Summary of Shortcomings

Weaknesses.—There are, then, weaknesses in our basic understanding of the estuarine and economic environments and of the resources with which we are concerned. Not only are there weaknesses of fact and of extent (detail, comprehensiveness, range) of basic understanding but also of technique. Our ability to conduct meaningful bioassays, using those marine organisms that are really critical (as opposed to being hardy and amenable to handling), to detect and analyze many natural and manmade substances, to provide effective instrumentation, and to mount adequate monitoring capability must be strengthened! Otherwise, baseline knowledge, criteria and standards, planning, operating, monitoring and enforcement will continue inadequate.

Improvements.—Sufficient improvements in these areas have been made in the last decade and a half to allow greater confidence in present criteria, standards, and management capability. We are doing better and can improve.

Research needs.—Unfortunately, we lag badly in support of meaningful background research, in development of better treatment techniques, and in training personnel and staffing waste treatment facilities. Improvements in these aspects are possible also—even now!

New forces.—New forces are upon us such as: a) the increased apparent need to develop new sources of energy by bringing Outer Continental Shelf oil and gas supplies into use; and b) the need to develop more nuclear generating plants, and other water-affecting energy facilities. In the meantime, with inflation and a declining economic situation, pressures to reduce or eliminate controls and management efforts, which undoubtedly add to costs of development and use, are growing! It is a great temptation today to forget environmental safety in order to reduce costs to meet an emergency of money, energy, and time—especially when many other countries have done so. To do so would be extremely foolish and short-sighted! We must resist the pressures! This can be done in part by increasing knowledge, tightening quality control specifications, and managing to closer quality tolerances.

Zero discharge—a nonviable concept.—It must be noted at this juncture, however, that the zero-discharge concept of waste disposal and the urge and effort to release to the environment effluents which are "purer" than the natural waters of the receiving stream are not reasonable or viable concepts. Both ideas have contributed to: a) the antip-

athy that the clean-water movement receives; b) a lessening of legitimate efforts to acquire much needed knowledge; c) a weakening of the development of improved effective management; and d) a certain false sense of security and accomplishment in legislation and regulation. This is not to say that it may not be technically possible to accomplish such objectives but it will be extremely costly for society to do so—even unnecessary.

A point of urgency!—Hopefully, the current economic downturn, the urge for economy in government, and the strong thrust for development of new energy sources will not result in reversal of the recent trend toward improving the ability to prevent pollution, or rather to contain it within reasonable bounds. We cannot afford unnecessary expenditures of money to achieve levels of environmental control beyond those actually required. Neither can we allow degradation of environment or unfettered use of resources!

CONCLUSIONS

The Current State of Estuaries and Coastal Waters

Headway in development of standards and controls and greater public awareness and concern has led to considerable improvement in ability to slow, even prevent, contamination of estuaries and coastal waters. Older cities, located on estuaries or coastal waters, such as Richmond, Va., and Washington, D.C., have stopped spewing raw sewage into the upper James and upper Potomac, or are supposed to have. The volume of untreated sewage and the level of treatment have both changed for the better in most places. However, in certain, even most, estuaries the trends of degradation continue and at a much faster rate than in other waters. As a result it must be concluded that, however effective the effort has been, we still lose more than we win. Thus, despite bright spots and the growth of understanding and the ability to control, the general quality of the waters of our estuaries and coastal waters taken as a whole is worsening—at a slower rate in comparison with the growth of populations and industry than 20 years ago—but still worsening.

The agencies, institutions, and persons who have been involved in the evolution of water quality criteria and standards deserve credit. American estuaries and coastal waters are in better shape than they otherwise would be. But all concerned must realize that additional efforts are necessary before we can prevent or reverse the processes of degradation as effectively as we must.

What Must Be Done?

Several shortcomings in ability to understand and to devise and bring about effective systems for controlling the quality of estuaries and coastal waters have been identified and described above. What must be done to reduce or eliminate them?

IMPROVEMENT OF RESEARCH AND MANAGEMENT

The need for additional knowledge of the estuarine environments and organisms in question and the forces that act upon, and especially against them, is clear. So is the necessity for improved management technology and organization. Additional financial support for research and development and for management applied in the right place is clearly required. It is beyond the scope of this essay to indicate in greater detail or more specifically where the needs for research and management are. It can be said, however, that water quality criteria for estuaries and coastal waters and for dependent biota and uses must be improved! To do so, additional effort at research and engineering development is necessary. As noted above, noteworthy effort was devoted by the National Technical Advisory Committee (USDI, 1968b), the NAS-NAE group (NAS-NAE, 1973) in "The Blue Book," and by the EPA Water Quality Group (EPA, 1973) in reviewing research and engineering needs and those publications should be consulted for details. Most of the needs identified in the excellent document, "Waste Management Concepts for the Coastal Zone: Requirements for Research and Investigation" (NAS-NRC, 1970) remain unmet. It, too, provides a well-developed guide to scientific and engineering requirements for all phases of waste-management related water quality work, establishment of criteria and standards, treatment, monitoring, and other aspects of management, technology, and operations. If the research and engineering needs described in these and other recent papers are carried out rapidly, management will improve soon. If they are not—it will be later! The same applies to improvements on a) organization for management, b) criteria and standards, c) waste treatment techniques, d) system design engineering, and operation, and e) monitoring!

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SEVEN WAYS TO OBLITERATION: FACTORS OF ESTUARINE DEGRADATION

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ABSTRACT

The most significant factor contributing to the degradation of our estuaries is our failure to treat an estuary as a natural system, rather than as a convenience serving man's many and conflicting purposes. This attitude is exacerbated by lack of competence on the part of consultants called upon to predict the results of interfering with natural processes they do not understand in the first place. When this is combined with notions of cost-benefit analysis and trade-offs that justify to ourselves the addition of deleterious substances and chemicals, alteration of temperature and sediment regimes, and spillage of oil, the synergistic action may accelerate the demise of an estuary.

INTRODUCTION

Estuaries have been a major factor in the development of civilization and man's institutions. As sheltered environments for the establishment of commerce and, for the most part, pleasing sites for settlement, estuaries provide the environment for most of the great cities of the world. Yet, they are also valuable resources for food gathering, and are the site of man's first attempts to farm the sea. They are often thought of as fragile environments but, if they were, they would have been destroyed long ago. It is the daily fluctuation and the regime of environmental changes, both tidal and seasonal, that protect the life of estuaries from excessive damage, at least from moderate amounts of pollution, for the life of estuaries is adapted to, and depends on the environmental fluctuations. The same mechanisms that make estuaries excellent nutrient traps and enhance their value to life also make them pollution traps, as emphasized by W. E. Odum (1970). There can easily be too much pollution and, most dangerously, combinations of various kinds of pollution that together may have much more effect than several factors acting singly. This synergistic effect is difficult to estimate and predict.

One of the most significant sources of environmental degradation in estuaries is not usually thought of as "pollution." This is man's habit of digging up estuaries for harbors and filling their borders and sometimes middle parts, for land on which to build docks, factories, and even residences. At least 10 classes of polluting materials are discharged into estuaries and coastal waters; some of these are sewage, heavy metals, organochlorine compounds, industrial effluents of all kinds, cooling water, oil, radioactive material, and inert dumped material from estuaries. Many of these can be treated together, e.g., chemical wastes of various kinds, although we do not understand the effects of many of them. There is also the danger that we may synthesize some extremely deleterious substance whose action will become apparent before we realize that we should never have produced it in the first place.

In this context, it is useful to consider some statements from a British report on estuarine pollution:

> In considering pollution in estuaries and coastal waters, we frequently met the assumption that pollution is not a hazard unless it directly endangers human health. We therefore emphasize that dangers to other forms of life may be no less serious. For example, if it were ever to become the case that a pollutant which inhibited the capacity of microorganisms in the sea to convert carbon dioxide to oxygen, or to break down organic matter, became widespread, this could be a menace. Concern for the eventual impact on man of the ecological cycle which ultimately sustains life is sometimes misinformed, but this concern is not mere sentimentality.
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> A great deal of pollution ends in the sea. Some of it is discharged through sewers directly into tidal waters; some reaches the sea through rivers. Some is carried into the air and brought down to the sea with rain; and some, including some very toxic wastes, is dumped in containers from ships. The sea is a powerful and effective scavenger of many pollutants, but recently biologists have become apprehensive about its capacity to deal indefinitely with the waste materials being put into it. There has already been enough degradation of the environment to justify this apprehension, notably in enclosed seas like the Baltic and the Mediterranean, which have very little tidal rise and fall.

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> Two attitudes to the problems of pollution in estuaries now confront the public. Contamination is without any doubt taking place and some estuaries are, by general consent, highly objectionable. Impressive quantities of offensive and, in some cases, potentially dangerous substances, are being put into them and out into the sea. Evidence is available to show that these discharges may damage or destroy shellfish, birds, and fish. The immediate emotional reaction is to urge that this contamination should be stopped and stopped at once, before it is too late to reverse the process of destruction.
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> The opposing attitude is to play down the harm that is being caused and to point out, with every justification, that the discharge of sewage and industrial effluent into the estuaries reduce the costs of industry by a considerable amount. Those who hold this attitude point out correctly that to eliminate entirely these discharges would throw a heavy burden on certain of the industries concerned and generally on the local community, sufficient in some cases to cause some enterprises to be abandoned and people to be thrown out of work. Simultaneously, they argue that the tangible benefits to be gained, which can actually be costed, are minimal, amounting to little more than what would be saved by reducing damage to inshore fisheries. They claim that no damage to human health has resulted from these discharges nor has any long-term danger been proved to exist. Granted that many people are offended by the squalid condition of some estuaries; that does not justify putting local government and industry to vast cost to remove the offence.
>
> The Commission's conclusion is that the truth lies somewhere between these two sets of views. However desirable it would be to remove contamination from estuaries, there is a practical limit to the burden which should be placed on the community to achieve this aim. This limit can be defined as the point beyond which the marginal cost of abating pollution exceeds the marginal cost of the damage being done by pollution. But the inputs for this sort of calculation are rarely at hand; so in practice, arbitrary constraints have to be put on the amount of pollution. This does not only mean the tangible measurable damage such as the loss of fishery production, but includes any loss of welfare that the community may suffer as a result of the pollution. In addition, it may be some time, even years, before the damage caused by certain forms of pollution becomes apparent.
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> (Royal Commission on Environmental Pollution, H.M.S.O., 1972.)

This rational view of the situation, as the commission concedes, constitutes an attitude of trade-off of potential sacrifice of life or environment that can be averted only by "arbitrary constraints." Too often, from the environmentalist point of view, constraints are relaxed in favor of the short-term advantage to man. Without clearly realizing the implication of this attitude, we are treating our fellow passengers on this planet, and the environment that supports us all, as secondary in importance to our own desires and as potential nuisances that get in our way.

ECOLOGICAL INEPTITUDE

One of the greatest endangering factors which contributes less to direct degradation of estuaries than to inadequate protection measures and improper restoration recommendations is a peculiar form of half-ignorance or lack of competence on the part of the consultants and administrating officials. This deficiency usually takes the form of oversimplified statement of ecological theory and a resulting doctrinaire approach to such matters as food chains or webs, viewing diversity index as a magic number for administrative purposes. The uninformed espouse the mistaken notion that because sea and estuarine organisms produce so many eggs and larvae that a loss of 99 percent is part of the course of nature, another small percent of loss of survivors can do no harm. Inadequate understanding of ecology is not peculiar to those involved with estuaries, but the estuarine situation is beset with many more pitfalls for unwary and inadequate ecologists than terrestrial and freshwater environments.

One would hope that such a statement as the following, made in behalf of releasing pollution in a bay instead of into the ocean, is exceptional, but similar gems from the soft paper literature suggest otherwise:

> More important than the argument of plant reliability because it deals with a false concept, is the argument of fragile ecosystem populations. Biologists recognize that a population that has a high diversity is more shock-resistant than one that has low species diversity. No matter what the shock that occurs to a highly diverse population, there is some species within that population that is capable of dealing with that shock. There is a great deal of give and take in a highly complex environment such as that found in the bay. The bay is, in comparison, a more diverse ecosystem than that of the open ocean, particularly in the case of such a limited aspect of the ocean as the near shore environment off the Samoa Peninsula. Indeed, environmentally, we must consider that the bay is more amenable to transient plant operation disruptions than is the open ocean. It is on this particular error that the whole policy failure of the State Water Quality Control Board rests, as have some of the mistakes of other public agencies in the past. It is true that many estuarine systems have suffered from hypereutrophication and toxicity due to various waste discharges, including municipal effluents. None of those estuarine situations are similar to that of Humboldt Bay. Humboldt Bay does not contain the freshwater-saltwater wedge that is present in most rivermouth estuarine systems. The populations of Humboldt Bay are not subject to a daily or twice-daily shock of fresh water and salt water which limits the number of species. They are composed of hardy forms that have evolved in a system of fairly uniform temperature, salinity and density gradients subject to minor shocks of freshwater and of heavy organic loads from freshwater streams; in short, situations very much like municipal sewage treatment facility effluents. These populations have evolved to handle such minor shocks and to utilize the nutrients provided to attain high

levels of productivity. Great diversity at the lower trophic levels of a system will be reflected in the high diversity at the upper levels of the system. It is very difficult to imagine, a system with its high productivity and high diversity at the upper levels of a system without a great deal of diversity and productivity in the lower levels of the system. One of the higher levels of a system such as that of the bay is the bird life. Birds eat the small marine animals that live on even smaller marine animals that live on the phytoplankton and the organic debris in the bay. Humboldt Bay is noted for its wildlife and especially for its waterfowl population which are highly diverse and very abundant. Birders come from all over the country to watch birds on Humboldt Bay. One of the favorite spots for watching waterfowl on Humboldt Bay is the sewage oxidation ponds of Arcata where the concentration is great and the diversity of species to be found is truly amazing. It can be easily inferred that the steps of the food web below the bird population are equally diverse, equally productive.

(Challenge of Water Quality Control Plan, North Coastal Basin 1B, 1974.)

The reasoning behind this kind of inept ecology provoked Michael T. Ghiselin (1974) to remark: "Undergraduate instruction and public policy, at least, are seriously threatened by ecological orthogenesis. It is as if we were teaching medicine out of Science and Health."

This may seem harsh, but much of modern ecology is a sort of glass-bead game of rarefied abstractions manipulated with algebraic dexterity into pretty designs of many colors by young men eager to impress their masters. The Glass Bead Game of Hermann Hesse's novel was an ironic parody of scholasticism withdrawn from reality; its greatest practitioner, the Magister Ludi, died in the icy waters of an alpine lake while trying to keep up with his last student. True, he had left the sanctuary of the Glass Bead players, but too late.

The problem is not so much ignorance as it is the great demand for ecological interpretation and administration, prompted by the concern for environmental protection. Proper or adequate determination of environmental conditions and estimation of the effects of man's intervention call for more informed talent than is currently available. Mere possession of a PhD does not of itself guarantee competence or even knowledge of the subject area, and some of the suggestions made in California by W. F. Libby and Chauncey Starr at UCLA to require certification of environmental specialists or to license consulting ecologists, as engineers are licensed, could blanket in unsuitable people.

Nevertheless, we do have too many self-styled environmental consultants whose qualifications are little more than a small sum of money to pay a printer's bill for letterheads and calling cards. Significant sums of money are paid to these people for inadequate environmental impact reports. They have committed themselves to predicting the effects of a process when they do not understand the process involved. Many of the people concerned are unaware of their inadequacies, serene in the delusion that since we all live in the same environment we are all qualified to study it. The complexities of environmental studies make it difficult to set standards and qualifications for consultants and experts, however. Perhaps many of the less endowed would retire from the field if they were required to reduce their fee at least 50 percent if their environmental impact reports were disqualified as inadequate by courts or hearing bodies.

Education in the basic concepts of ecology is needed urgently. There has been too much haphazard and inadequate teaching by persons whose own grasp of ecological problems is inadequate and incomplete to begin with. Perhaps we need a concise text book for administrators and hearing officers, a guide to the interpretation of environmental impact reports. Yet, it would seem that there has been enough bad ecology in environmental assessment and impact reports to inspire the judicious skepticism necessary for interpreting inadequate work. Obviously, our greatest scarcity in this, as in so many other problems, is that rare commodity, horse-sense.

Nowhere is ecological ineptitude more clearly demonstrated than in the notions of cost-benefit and tradeoffs. An economist who suggests that we set a money value to the fish or amenity that may be destroyed by a power plant, and submit the cost-benefit ratio to a public vote, is proposing an evil and senseless procedure. This notion that we can assign money values to such diverse matters as clean water, fisheries, pleasing scenery, kilowatts, and parking lots is a recent contribution of man's hubris, especially when we make a decision on the basis of this arithmetic of apples and oranges that may extirpate other species from the scene and set irreversible ecological decay in motion; this notion is reprehensible. The idea of assigning a dollars and cents value to life—any life—can lead to the end of life on earth as it now does to the exhaustion of non-renewable resources, a mining-out of life as if it were some raw material. This approach to the problem of environmental insult assumes that the processes of nature are simple and can be safely tampered with in terms of our idiotic anthropocentricism.[1] Not only may we destroy one or several species, we may destroy gene pools by obliterating "worthless" wild relatives of cultivated

[1] Vide the graded scales of "one-ness with nature," "sense of awe," etc., in Dee, 1972.

or exploited stocks. We are—or should be—aware of the danger of this in agriculture where we have produced plant varieties incapable of adjusting themselves to change in an artificial ecological system. In fisheries also, we need reservoirs of wild genetic stocks against inevitable ecological change.

Another danger of this cost-benefit approach is that we do not know, in many cases, the key species in an ecological system and we could vote or recommend a significant species out of existence without being aware of what we have done until an irretrievable loss has occurred. To think of economics in this sense as hard and objective is a mistake, for in the field of cost-benefit analysis, economics is the squishiest and most subjective of human thought processes. It leads us to the position that in times of economic crisis we cannot afford to preserve the environment or our fellow species as we must maintain our standard of living, even if it is our standard of living that has brought us to this crisis with national resources.

In 1864, George Perkins Marsh, formerly a member of Congress from Vermont and for 20 years ambassador to Italy, published his famous book, "Man and Nature." In this book, he predicted that if mankind continued his misuse of the earth at a like rate as he had done since civilization began, the earth would become unfit for human habitation in about the same period of time. In Marsh's day, they thought that civilization was perhaps 5,000 years old. But our abuse of the earth has increased exponentially in these last 100 years so that our time has been reduced, at least an order of magnitude, from thousands to hundreds of years. At the rate we are going, our children may be the last human generation on this earth.

It is too precious a refuge from time to be subjected to the irrelevancies of ill-informed economists and incompetent ecologists; if we are to survive at all, we must drive these miserable moneychangers of cost-benefit analyses, trade-offs, and externalities out of our temple.

We talk of the "needs of man." What are they? If we put the survival of a species to a vote—and in such an election, all must vote who lead lives of quiet desperation—it is the inevitable step to the destruction of the quality of environment that man needs to continue his "standard of living." In the end, man will drink water from his sewage plants, breathe the exhaust of his factories, and reside on his own garbage heaps. Henry Thoreau, writing in his journal on April 11, 1857, foresaw it all:

> The very fishes in countless schools are driven out of a river by the improvements of the civilized man, as the pigeon and other fowls out of the air. I can hardly imagine a greater change than this produced by the influence of man in nature. Our Concord River is a dead stream in more senses than we had supposed. In what sense now does the spring ever come to the river, when the sun is not reflected from the scales of a single salmon, shad or alewife? No doubt there is some compensation for this loss, but I do not at this moment see clearly what it is. That river which the aboriginal fishes have not deserted is a more primitive and interesting river to me. It is as if some vital quality were to be lost out of a man's blood and it were to circulate more lifelessly through his veins. We are reduced to a few migrating suckers, perchance.

FILLING AND DREDGING

No factor affecting the degradation of estuaries is more permanent than filling. Once filled, for whatever purpose, an estuary is no more, and even partial filling can have serious consequences. The other side of this coin is dredging; sediments dredged to maintain channels and turning basins or to provide access to docks must be put somewhere, and often they constitute a valuable addition to waterfront real estate from the viewpoint of commerce, navigation, and industry. Indeed, it is the chief interest of harbor commissions that undesirable tidal flats be converted to useful real estate as rapidly as possible. In recent years, however, we have become aware that filling is a kind of pollution and that a tacit national policy of filling all available tidelands is in the long run not in the national interest. We have only so many estuaries, and their prime importance, both to commercial fisheries as nursing grounds for the young of various stocks and to the recreational fisherman, dictates a much more stringent policy on dredging and filling than we have had in the past. Yet, it was not quite 70 years ago that Nathaniel Southgate Shaler (1906), otherwise a man before his time in many of his environmental concerns, could write:

> There are in all the great lands vast areas of lakes, swamps, and marshes awaiting the skillful labor which has won Holland from the sea. The largest opportunity of profits is in such brave combats with the incomplete work of nature.

Shaler was not a biologist, although he was one of the moving spirits behind Agassiz's first seaside laboratory experiment at Penikese, so he perhaps could not have been expected to realize that the margins of the sea, the marshlands, and the tidal flats constitute essential parts of nature's natural system, and are not her incomplete work to be polished off for man's economic benefit.[3]

[3] Agassiz's concept for the future of Penikese as a center of practical application of studies of "fish . . . oysters, lobsters . . . ." is a startling anticipation by a 100 years of the present sea grant program. See Edward Lurie, "Nature and the American Mind" (Science History Publications, New York, 1974), pp. 59–60.

It is this aspect of dredging and filling, the destruction of the margins, or separation of them from the waters of the estuaries, that is most serious. Much of the nutrient source for the maintenance of estuarine life comes from the runoff across the marshlands and upland borders, yet often such wetlands are not protected by restrictions on dredging and filling. Referring to these areas as "wetlands," as if they were separate from the estuaries, is a mistaken classification. It is the reduction of the wetlands and of tidal access to marshes, as much as the filling itself, that has resulted in the $1.4 million estimated loss to fisheries in Boca Ciega Bay since 20 percent of its surface area has been filled, primarily for the development of small boat facilities (Taylor and Salomon, 1968). The combined factors related to the loss of fisheries value are the reduced bay volume, disturbance of bottom by dredging and bulkheading (which also separates the borders from tidal action), and consequent impaired tidal action.

There are many examples of piecemeal, bit-by-bit filling in our estuaries; it was considered the best thing to do with the shallower parts of bays, and subsequent efforts to unfill illegally filled or obliterated tidelands have not been successful. Such an area as Pony Village in North Bend, Ore., was built by filling the upper end of Pony Slough, without so much as by your leave. A large shopping mall, a motel, and several acres of paved parking space are difficult to retract.

Concern for preventing further encroachment of this kind in San Francisco Bay led to the establishment of the San Francisco Bay Conservation and Development Commission in 1965. At that time, it was realized that more than 250 square miles of the original open water surface of San Francisco Bay had been filled, and more was in prospect. One project would have cut down a large part of San Bruno Mountain to fill in areas near the San Francisco Airport. Among the possible effects of such a continued haphazard filling of San Francisco Bay could be a loss of the climatic amelioration related to the surface of San Francisco Bay itself; in short, if there were to be no bay, there would be no bay area. A public action movement led to the establishment of the commission, although the legislature was at first reluctant. The commission, consisting of representatives from state and local agencies as well as public members, has jurisdiction over filling. Unfortunately, its jurisdiction includes only the bay and harbor development, not the entire estuary system. It has undoubtedly prevented some excesses, but as the interests of the membership become more vested, it shows signs of losing some of its original missionary zeal and fire. So it is often with public bodies, no matter how high-minded.

Unless, of course, they are harbor commissions. These bodies are always concerned with developing ports and harbors. Quite often, the development is related to the personal interests of some of the members, but it would be impossible to form such a body otherwise. In some parts of the country, it would appear that there is not enough disinterested and knowledgeable talent to staff the commissions, yet these commissions often have powers that are greater than those of any other local bodies, since they are responsible for state lands. Some years ago, the Harbor Commission for Bolinas Lagoon, a small marine embayment just north of San Francisco, planned extensive marina development which would have completely changed the character of the lagoon. As a result of public outcry, the Harbor Commission itself was abolished in 1969. This ought to happen to more small harbor commissions which forget that they are in charge of a living environment, not potential marina property.

DIVERSION

Since an estuary is a region mixing fresh waters of terrestrial origin and saline water from the sea, it follows that diversion of fresh water in significant quantities will change the character of the estuary system involved. Diversion of all the fresh water would turn an estuary into a marine lagoon; in such an event, the productivity base of the system would depend entirely upon the neighboring sea and the vagaries of tidal exchange. Such systems, as exemplified by the saline lagoons of south Texas, may fluctuate and be less dependable in their fisheries resources than a well-balanced estuarine system. Yet, major diversions have been proposed for the Texas bays and, while these may be pipe dreams of engineers, one cannot forget that such ideas have been proposed and that, in one case, are well on the way to fulfillment unless there is a drastic change in water policy.

This is, of course, the diversion of water from northern California to putative agricultural lands of the San Joaquin Valley and the megalopolis of Los Angeles. The diversion is to be accomplished by an elaborate bypass system, called the Peripheral Canal, around the delta (confluence) of the Sacramento-San Joaquin Rivers. The diversion scheme has proceeded in the absence of sound environmental or hydrological information; it is considered impossible, for example, to compute the volume of water that flows out of the delta into San Francisco Bay, because of the complex nature of channels, sloughs,

and streams. Estimates of diversion of water to Los Angeles that would leave perhaps about 50 percent of the net outflow required to maintain water quality and protect fishlife aroused alarm and stimulated lengthy hearings before the California Water Resources Control Board in 1969–1970. The upshot of these hearings was Decision 1379 (1971), which recommended substantial increases in flow from the delta in low water periods, which would reduce the diversion to the southlands desired by the California Department of Water Resources by perhaps 0.9 million acre feet. Decision 1379, which in effect recognized ecological water rights, has been considered a landmark decision, but it has been bitterly opposed by the diversion interests and is under appeal. In the meanwhile, the Department of Water Resources has issued its environmental impact report on the Peripheral Canal, contending that all will be well if water is released in a sort of bleeding action at various places along the canal into the delta system.

In all, the EIR for the Peripheral Canal has not satisfied everyone and, most conspicuously, there is not an adequate assessment of the impact of the vast quantities of electrical energy needed to operate the pumping system upon the economics of the diversion and other energy needs.

There are other ways to accomplish diversion of water from an estuary besides turning the water into a ditch to be carried away. Our concern for protecting estuaries from temperature increases from cooling waters may result in practices that could in the long run achieve the same effect by reducing the volume of river flow. Proposals for power generation in the Susquehanna Valley, for example, could lose large volumes of water by evaporation in closed circuit cooling systems and towers, perhaps amounting to a third of the low-water flow of the Susquehanna, one of the major tributaries of the Chesapeake Bay (Olson, 1974).

Such a possibility suggests that more serious consideration be given to reducing evaporation loss in cooling systems; certainly, the great battery of cooling fountains at the Pacific Gas and Electric cooling ponds at Pittsburgh function admirably as evaporators. Large numbers of such cooling systems, combined with the flow reduction for the California waterworks, might increase the loss of water to the system by unacceptable amounts.

Not long ago, it was suggested in Oregon that, because of the scarcity of fresh water in many coastal regions during dry years, entire streams be diverted from above tidewater during the summer months. It was thought by whoever made this suggestion that the estuaries were not being used by fish and other life during the summer months, so that there would be no serious effect on the estuaries!

One of the serious aspects of diversion of water is the reduction of the natural sediment load of streams flowing into bays and estuaries. As brought out in the hearings about the diversion of water from the delta in San Francisco Bay, this reduction could have a serious effect on primary productivity and the ability of the estuary to handle pollutants, since fine sediment particles protect the waters from excessive sunlight and function as scavengers by bringing down heavy metals when they flocculate on reaching the saltwater part of the estuary.

In this context, it is not encouraging to find that detailed consideration of altered sedimentation processes has been omitted from the environmental impact report on the Peripheral Canal prepared by the California Department of Water Resources. One is reminded that the excessive sediment loads in San Francisco Bay from hydraulic mining were not stopped because they were shoaling the bay and altering the tidal prism as a consequence (Gilbert, 1917), but because the mining debris was destroying farmlands.

A point often forgotten about natural sediment loads in our estuaries is that the heaviest occur during the runoff season, when river temperatures are lowest. A similar heavy sediment discharge or accelerated erosion in summer, from construction activities or farming is deleterious to the life of an estuary.

CALEFACTION

Calefaction, the process of making things a bit warmer, was dredged from the dictionary by Daniel Merriman a few years ago (1970a). The idea implicit in Merriman's usage was that a little calefaction did no serious harm; the increases in temperatures associated with the power plant on the Connecticut River that was his principal concern were not causing any significant change in the sequence of events, except that some catfish were not doing well. But the Connecticut River in the region of the power plant in question is subject to tidal action and the thermal plume did not really calefy the river. So, in the sense of increasing the temperature of the environment, there was not any real calefaction at all, and the observed effects could be just as reasonably attributed to entrainment, the drawing in of water through the plant, and to scour from the steady effluent current from the discharge outfall of the plant.

Nevertheless, calefaction is a real concern and we are aware of situations where temperature increases

from the use of environmental water as a coolant may reach significant values. Furthermore, while the present scale of operations may not have serious effects on open coasts, our increasing reliance upon coastal water to cool down the exponentially expanding power-generating installations suggests that the time is not far off when we may anticipate significant changes in nearshore temperatures. A few massive power plants here and there, releasing warmer water into a small region near the outfall may have no real effect except upon the organisms ground to bits within the plumbing, but arrays of ever larger generating plants pumping significant percentages of the nearshore currents of an open coast or of an estuary into their condensers and release of the warm water into the environment may cause a serious alteration of the environment.

It was suggested, for example, that our engineering capacity might make it possible for us to construct perhaps 4,000 nuclear parks along the shore to utilize coastal water for cooling purposes (Weinberg and Hammond, 1970). A series of power plants on that scale, designed to meet all our exaggerated demands for energy by supplying power to 20 billion people at our present rate of consumption, would undoubtedly change the character of coastal waters. It would also seem that such a bulk of people would of itself increase the temperature of the earth. One would like to think that the authors had a satirical intent and did not really believe their own estimates, since they gave no serious thought to possible effects on nearshore circulation patterns or plankton populations. Some lip service is given to ecological considerations in a brochure titled "Siting Considerations for Offshore Nuclear Power Plants" (Dames and Moore Engineering Bulletin 42, 1973); it is stated on p. 31 that "part of the overall objective is to see whether the site is sufficiently decoupled ecologically from . . . associated estuarine systems."

Temperature is a relative measure of the amount of heat, and heat is the energy of molecules in motion. The lowest possible temperature would be that of the situation in which there is no molecular motion, or −273.15°C (0°K); at the other extreme, the temperature of the sun is several thousand degrees. Temperatures in the sea range from −2.0 or −1.8° in the deepest trenches and near surface Antarctic waters to over 40° at the surface in semi-enclosed tropic waters such as the Red Sea. The average temperature of all water masses of the world ocean is about 3.9°C.

No form of life that we know can withstand the extremes of absolute zero or the heat of the sun, and the range of temperature encountered in the sea and estuaries is but a small fraction of the range of conditions that occur on land. Very few organisms are adapted to survive even a small part of the total range of temperatures occurring in the sea. Many of the organisms of the Antarctic and abyssal seas experience temperatures within the narrow range of about −2.0 to +1.5°C or so, whereas species of shallow tropical waters may live within the range between 20 and 30°C. Most organisms appear to be able to withstand short period extremes of temperature; such tolerance depends upon other factors in combination with the temperature rise or fall, such as oxygenation, or reduction of internal temperature by evaporation in intertidal species. Many organisms can adjust themselves to long-term altered temperatures, within certain limits; such adjustment is called acclimation. Many others are adapted to regular variations or seasonal temperature cycles. Others, we suspect, meet the temperature variations in nature, especially those associated with changes in strength or position of currents, turbulence, and internal waves by producing an excess of reproductive stages, most of which are sacrificed to environmental vicissitudes. Therefore, we must consider the temperature regimes of each situation somewhat differently.

With respect to the attrition of reproductive stages, it cannot be assumed that because 99 percent of the young produced by a species are lost, we may safely levy upon the remaining 1 percent. For many organisms, the cleavage stages may be most sensitive to temperature, and later stages progressively less so, but the vulnerability of all stages suggests that exposure to artificially high temperatures should be as short as possible. And, while the adult may be the least sensitive, it must produce this vast excess of young to ensure at least one adult survivor for the next generation. A single reproducing adult (or a pair) may not be enough, conversely, to establish a new population, as demonstrated by the many failures to establish exotic species.

Some critical mass of reproducing adults seems necessary to establish populations in new waters. Thus, at both ends of the logarithmic curve of population, matters are difficult for survival in nature; whatever the optimum may be, the sea is not a benign and undemanding environment, but quite the reverse.

It would be impossible to summarize the extensive literature on studies of the effects of temperature upon organisms in anything less than a large book, yet this work taken together leaves something to be desired when we try to understand the actual relations of temperature to organisms in the environment. Environmental events usually have not been synchronized with laboratory tests and seldom have

experiments taken into consideration the fluctuating regimes of the actual environment. As with many other factors, laboratory tests are simplifications or abstractions which may give us clues to how or why things happen in nature, but fail to explain what may really be happening.

Now, to the sometimes irrelevant data of experimental physiology, we have added the even less relevant data of environmental impact studies. Too often, such studies are beside the point and leave the basic problem untouched. For example, an investigation of the possible effects of a warm water effluent on shallow water organisms presents temperature measurements of the uppermost surface layer taken by a distant infrared sensor, and lists of species, numbers, and size classes of invertebrates living from several centimeters to perhaps two or three meters below this measured layer, or within the sediment still further removed from the surface layer. Values are correlated and regression lines drawn, indicating as might be expected that there is no relationship between surface effluent temperatures and the biota beneath. Unfortunately, the conclusion is then offered that the altered temperatures have no effect on the biota, a conclusion that cannot be substantiated by the data offered (Adams, Price and Clogston, 1974).

Such misleading interpretations of inadequate data are far too common and there is little to choose between this quasi-scientific approach, often invested with the trappings of quantitative ecology, and the public relations interpretation that the warm water effluent outfall of a power plant enhances fish life. The latter approach is based on the observation that more fish may be caught there than in other parts of the nearby environment. However, this rationale fails to make it clear that perhaps the power plant site may be the only place at which fishing is possible along that part of the waterfront; nor does it point out that nowadays such fishing is welcomed, to promote the idea that fish are thriving there or that a parking lot for company employees is open to visitors who desire to fish during off hours.

Much of the literature of physiological responses to temperature by fishes and invertebrates is difficult to interpret without adding this kind of logic to the confusion. Too often, experimental data is based on restrictive conditions not typical of what is actually happening in the environment. A lethal temperature for sea urchins may be demonstrated in the laboratory that is below the actual conditions under which the species may survive at low tide in nature, because the cooling of the animal by evaporation and its access to abundant oxygen are factors eliminated from the experimental protocol. Even more significantly, the range of variation, the rebound from very warm conditions at low tide to the daily immersion in water many degrees cooler, is not taken into consideration. The situation is extreme in estuarine and intertidal organisms; many of these, however, are the organisms most likely to be within range of a warm water plume from a power plant.

It must be remembered that while there may be no direct relation between a warm surface temperature and the organisms only a few centimeters below, the surface layer is one of the most biologically active regions of the sea, and that what happens in this interface between sea and air ultimately affects all life in the sea (MacIntyre, 1974). Thus, while some fish or clam or other invertebrate may well withstand the increased temperature of a power plant and perhaps survive a trip through the condenser tubes, the real impact on the environment may be of a different order entirely, subtle, not easily measured, and not perceptible for perhaps several years. Here in the active surface layer is the *mare incognitum* of calefaction. Tentative evidence suggests that there may be danger of interfering with the basic productivity of the system, which would be far more serious than Merriman's "marasmus of catfish."

The literature on thermal relationships of organisms is a tide that shows no sign of ebbing. Coutant and Goodyear (1972) listed 394 references, most of them published during 1971. The application of much of the experimental work to practical problems of thermal alteration is debatable, as the authors emphasize:

> Determining the tolerance of aquatic organisms to temperature extremes, both upper and lower, is a common experimental goal which has been given new relevance by thermal discharges from the electric power generating industry. In principle, the data obtained should have predictive utility for managing thermal discharges for minimum ecological impact. . . . Critical study of the reports published largely in 1971, however, indicated that any predictive utility is severely hampered by the plethora of experimental methods employed in the laboratory and the wide divergence of the quality of field observations. . . . Anyone wishing to use tolerance data from most of these reports must certainly read in its entirety the experimenter's paper in hopes of finding a rationale for that particular methodology and the particular limitations of results.
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> (Coutant and Goodyear, 1972, p. 1263.)

The barrage of impact studies, pre-operational surveys of plant sites, and luncheon speeches circulated in mimeographed form that comprise such a large part of the soft paper literature suffer similar defects without even the purgative of editorial review.

Natural temperature regimes, the seasonal variation from cold in winter to warm in summer, are not consistent and undeviating from year to year, although much of the discussion of thermal alteration of the environment by human activity would imply that the only change in the environment is that possibly induced by human agency. As with the terrestrial climate, however, temperature changes in the sea vary in their onset throughout the seasons, and often in unexpected ways which may be related to the global climatic fluctuations. Variations in temperature of the seas are often in the order of two or three degrees above or below the yearly average. There appears to be some relation between such small magnitude temperature changes and the success of major fisheries stocks; the catastrophic decline in the abundance of the California sardine may have been related to changing temperatures in the 1940's along the Pacific coast of North America. We do know, for example, that the eggs of the California sardine hatch most rapidly at 17°C. and that a decrease of 1° adds six hours to the hatching time, so that at 15° the hatching period is increased from 54 to 77 hours. It was estimated that a 3° decrease in temperature (and since the sardine egg floats at the surface, these are surface conditions) during the period of hatching and development of the larvae could decrease survival of the eggs by as much as 10 times.

The world's climate may be in a warming phase, according to some meteorologists, whereas others with equal reasonableness have announced that the present warm interglacial period has about run its course and within a few hundred years (or millenia) the glaciers will be back. The prospect of climatic change induced by man's industrial activities is also seriously considered by such authorities. A number of proposals for tampering with the earth's thermostatic system, the ocean—including the rearrangement of the freshwater supply of North America, Africa, and Siberia by massive impoundments and canals—could have unanticipated effects on coastal and estuarine environments of the regions concerned, since the freshwater contribution would be severely reduced.

Proposals for tampering with the regime of the sea itself include the Bering Strait Dam, which would, it is hoped, result in warming waters of the Arctic Ocean, although some oceanographic opinion suggests that such an effect would be masked or negated by the natural variations of the Atlantic water flowing into the Arctic Basin.

In view of the natural fluctuations in the sea and possible major interrelations between events in the northern and southern Pacific Ocean masses in particular and the climatic variations within historic times in many parts of the ocean, one may well ask why we should be concerned at all over a little calefaction. The problem is that our meddling with the climate, inadvertent or deliberate, may result in temperature anomalies that are out of phase with environmental events. This is essentially what happened in England where an attempt was made to domesticate the eastern American hard shell clam (quahog, *Mercenaria mercenaria*) in the warm effluent of a power plant adjacent to a sewage treatment works. Here was a situation where everything seemed right: a source of warm water, a source of carbon dioxide, and nutrients for plant growth. But the larvae of the clams could not be held in place, and were produced out of phase with the natural cycle of the adjacent sea.

It should be emphasized also that maintenance of stable temperatures in such situations may depend on the operating conditions in the power plant, that such conditions depend on the demands of industries and municipalities, and that these demands may at times conflict with the seasonal requirements. During the summer, for example, power demand may be reduced and the schedule of plant operation reduced, with a resultant drop in delta T at the outfall; on a cold upwelling coast such as Oregon, where upwelling is most intense in midsummer, it might prove uneconomical to operate in accord with the temperature demands of the local shrimp or mussel farm.

Or, for that matter, to maintain artificially altered local environmental conditions for the benefit of the acclimated fauna. This is illustrated by an episode in the Chesapeake Bay where fish, attracted to a warm water effluent, were killed by cold water during a shutdown of the power plant in winter.

Our present knowledge of the subtle and intricate relations of life within the environmental ranges of temperatures in which they have evolved and become adapted is inadequate to reassure us that even a little calefaction can do no harm. In his effort to reassure us that the warm water effluent of the Haddam's Neck power plant is doing no real harm to the environment or its biota, Merriman (1970b) nevertheless suggested that the present limits were about as far as we should go. Certainly we can exceed biological limits with very little increase in temperature in the tropics where the marine biota is already living near its upper limits of tolerance. Who knows what the effects of warming the Arctic might be upon slow-growing organisms adapted to low temperatures? Inevitably, artificial calefaction will be subject to fluctuations because of the added perturbations and off-and-on phases associated with opera-

tion of the associated machinery. The limits of calefaction may be much lower than we think.

From the viewpoint of a naturalist, it may not be only the amount of temperature change we may bring about, but the rate of such changes which may have unforeseen consequences on the biota of our coastal seas and estuaries. So much of our data is tentative or applicable only to individual specimens or species that we must be conservative about the effects of potential calefaction upon communities or the interactions of animals in nature. We are told that "we do not have the time to wait" for such understanding, which is the same as saying "we do not have the time to consider the consequences of our action." Such anthropocentric arrogance! Do we really have the authority to tell the rest of organic life that their future is contingent upon our immediate understanding of what our needs may be?

It must be reemphasized that, with respect to tampering with the phenomena of nature, the viewpoint of the naturalist is profoundly different from that of the engineer. The engineer approaches such problems with an attitude of complacence, or with the assumption that if what we do is bad, we can change or stop what we are doing. The naturalist knows that life is not a reversible process—an environment to some extent, and a species absolutely, once destroyed, cannot be restored. A "try it and see" attitude about any pollutant inimical to life processes is profoundly dangerous. Calefaction cannot be considered an exception, even where it might seem most permissible, in our coastal waters. The naturalist can only view changes in temperature as he does all pollutants, as potentially damaging unless proven otherwise.

SEWAGE: ORGANIC POLLUTION

Pollution of rivers and estuaries by man's effluvia has been with us since the establishment of cities, but wholesale release of wastes in liquid form as domestic sewage is a comparatively new environmental factor. To the extent that sewage consists of readily biodegradable or natural substances, its effects may not be irreversible and, in time, estuary systems heavily polluted by sewage may recover. Recovery is apparently now happening in the Thames River, which, a century ago, was a foul-smelling distressing mess, but to which fish are now returning. This is not to say that we can continue to pollute estuaries indefinitely with sewage, under the notion that, once we stop, all will be well. Excess production of blooms and large biomasses of not-altogether, desirable species may result in the

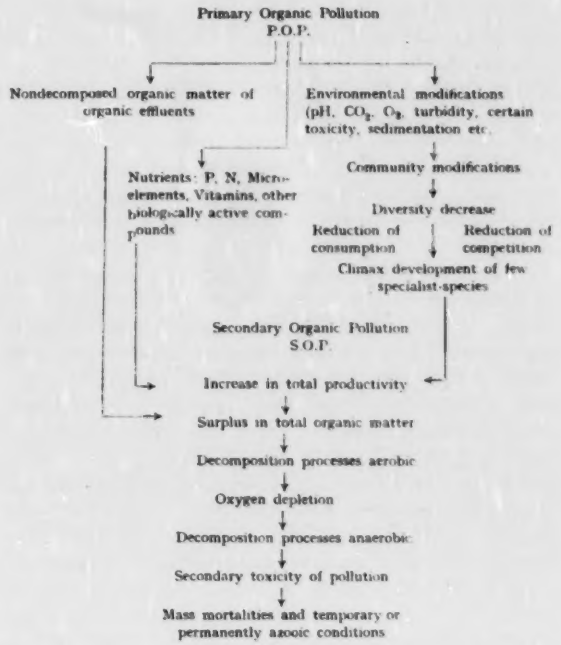
Primary Organic Pollution
P.O.P.
Nondecomposed organic matter of organic effluents
Environmental modifications (pH, CO_2, O_2, turbidity, certain toxicity, sedimentation etc.
Community modifications
Nutrients: P, N, Micro-elements, Vitamins, other biologically active compounds
Diversity decrease
Reduction of consumption
Reduction of competition
Climax development of few specialist-species
Secondary Organic Pollution
S.O.P.
Increase in total productivity
Surplus in total organic matter
Decomposition processes aerobic
Oxygen depletion
Decomposition processes anaerobic
Secondary toxicity of pollution
Mass mortalities and temporary or permanently azoic conditions

FIGURE 1.—Schematic presentation of processes of organic pollution and its consequences in marine environment (Stirn, 1973).

extirpation or elimination of more valuable species to such an extent that their return to a revitalized estuary may be long delayed or impossible (Figure 1). Bascom (1974) has suggested that the ocean is the best place for our effluents, but it is still too early to be certain that massive releases of excess material will be processed for us by the ocean without some damage or alteration of the natural system.

In any event, we have come to the position that estuaries are not the best place for untreated sewage outfalls. There seems to be no deleterious effect of disposing unprocessed human sewage in the cold waters of Cook Inlet, Alaska; at least, the major factor in the inlet is tidal exchange, rather than biological processes within the system. However, the capacity of the inlet is said to be finite, and not adequately understood (Murphy, 1972).

It is often pointed out that we may be wasting valuable material by open ocean disposal and that excess discharges into bays must be prevented. A recent statement of the case for use of our wastes in mariculture is that of Joze Stirn (1973):

> In my opinion, a theoretically ideal solution for sewage disposal would follow these requirements: effluents should not have a destructive influence upon marine ecosystems, which happens as a rule in quite large territories encircling underwater outfalls, and they

should not accelerate uncontrolled and useless eutrophication, which is also the case whether the effluents have been previously treated or not. This leads to undesirable changes, including aesthetical and sanitary ones, particularly and in a drastic way, in shallow coastal waters, i.e., in these parts to which the recreational activities and with them the important growth of the national economies as well are focused.

Sewage-born nutrients, including biologically active organic compounds, should be saved and returned to bioproductive processes in a way which could enable their utilization as food for the growing human population . . . . an optimal solution might be found within a potential possibility of developing a combined treatment-mariculture technology. There is of course no ambition of using this idea as a universal suggestion, which it cannot be, among others, because of a particular reason: for every coastal mariculture, an adequate geomorphological formation (bay, fjord, estuary, abolished salinas, lagoon) has to exist, available for this purpose, and out of competition of space with more rentable industries. Considering the Mediterranean or similar areas (where the mariculture has to be promoted anyway), we are dealing from this point of view with an enormous number of adequate geomorphological formations, located as a rule just in the economically passive (excluding tourism) territories, many of them desert, whether real ones in the south or karstic barelands in the north and in the east.

Such direct use of organic wastes in maricultural projects will not of course take care of all the organic wastes generated by man and processed in sewage plants, and use of solid wastes on land has been and should continue to be a significant application of this valuable resource. Nevertheless, we have not progressed far since the extravagant waste of this valuable resource in France was so eloquently denounced by Victor Hugo in "Les Miserables:"[3]

Paris throws five millions a year into the sea. And this without metaphor. How, and in what manner? day and night. With what object? without any object. With what thought? without thinking of it. For what return? for nothing. By means of what organ? by means of its intestine. What is its intestine? its sewer.

We fit out convoys of ships, at great expense, to gather up at the south pole the droppings of petrels and penguins, and the incalculable element of wealth which we have under our own hand, we send to the sea. All the human and animal manure which the world loses, restored to the land instead of being thrown into the water, would suffice to nourish the world.

Sea disposal of recyclable organic wastes is not the extravagance that Hugo supposed, however, for we do owe the sea some of its substance and the steady drain of protein from the sea in our great fisheries should be repaid. But it is not economical to take it back to Peru, so we dump it into the sea at New York, Los Angeles, and other great maritime centers of population. A far greater waste would be to discharge purified fresh water into the sea, yet some water quality requirements have approached this extravagant ultimate.

[3] "Les Miserables" was published in 1862. The two paragraphs quoted are a small part of the panegyric to the sewers of Paris, from Jean Valjean, the last book of the novel.

ALL OTHER CHEMICALS

We throw everything soluble (and often the insoluble substances as well) into our streams and estuaries; our rivers may "wind somewhere safe to sea," but with a burden of substances alien to the environment as man knew it barely 200 years ago. The era of affluence and effluence is still in its beginning and, while it may not last much longer even in the terms of human history, the potential damage from the complex of chemical wastes we are producing is incalculable. Even in the terms of a human lifespan, the effects of a particular substance are difficult to assess, because it may take 25 or 30 years for a cancerous condition related to some substance to develop, or at least to be noticed. We do not know what we are doing, yet if everything does not turn up dead because of some chemical we discard into the estuary, we seem to think we can continue to dump it.

There seems little point in discussing all the possible kinds of chemicals individually (as opposed to natural or quasi-natural organic substances that result from the excretion or death of organisms); they include the unusable or economically unretrievable wastes of our advanced and complicated chemical industry as it operates along our watercourses—from pulp mills to petrochemicals from the growing plastics industry. This last industry, it might be noted, is based on the wastage of resources in all sorts of plastic accessories and containers, and evidently assumes free disposal of all this junk to the environment. It may not be long before the most common object dredged from our estuaries will be the plastic ballpoint and felt-tip pen cases that are produced by the millions. It is now impossible to walk along an ocean shore without finding a few on any given day. I have picked up disposable syringes and discarded ballpoints at Punta Espinosa in the Galapagos; discarded, I am sorry to say, by visiting scientists.

Toward the closing years of World War II, we released four categories of pollutants into the environment which we now realize as deleterious to life: radioactive isotopes from military and industrial uses, antibiotics (sulfa drugs and others), insecticides (such as DDT), and detergents. To these Four Horsemen of the Ecological Apocalypse, we have since added a Fifth, the effluvia of our plastics industry, the polychlorinated biphenols, chlorides, and all the solid bits and pieces that are now turning

up in the surface layers of the ocean, far from land. It is difficult to decide which substance may produce new and greater dangers to aquatic life. Many of them persist for years, and may surface in unexpected places with unanticipated effects. It is not easy to estimate the significance of potential pollutants in the sea and estuaries, as indicated by a recent study conducted by the National Academy of Science (Goldberg, et al., 1974).

Always remember that we develop pesticides and herbicides to kill things. We apply tons of them to farmlands, gardens, and marshlands every year; by 1972, 390 or more kinds of chemicals were used to kill or control unwanted organisms. It says something for the ecological viability of many of these pests that we must continue to use noxious substances to get them out of our way; at the same time, we risk destruction of other forms of life which we may not be able to afford to lose from our environment in the long run. As for the pests, their ecological viability depends primarily on the ideal conditions we have set up for them, especially in our vast areas of single crop agriculture. Conversely, we must also add fertilizers to keep the crops growing, and if we do not continue this double jeopardy of fertilizers and biocides, the whole artificial system collapses into the diversified but less immediately productive system of undeveloped or preindustrialized agriculture.

As we continue to keep our chemists busy developing new and more deadly substances, the danger that we may develop some universal biocide increases. Insecticides developed specifically to kill arthropods may in time kill off many arthropods in estuaries and seas; some herbicides may sterilize a stream of all arthropod life. Yet, too often we find out about the effects of these substances after they have been tried out, not before. It is admittedly difficult to decide what effect, if any, new substances being synthesized and put to use may have; for one thing, many industries keep their processes private and it is difficult to determine what some proprietary substance is, or what processes may produce dangerous chemicals. The long generation time of some diseases in man and of the induction of ecological imbalances also make estimation of the effect of a newly-synthesized chemical difficult.

In a general way, the chemical pollution of estuaries consists of the following kinds of substances:

1. *Heavy metals*, e.g., mercury, zinc, copper, cadmium, primarily from industry, but in some cases, as probably in San Francisco Bay, much of the mercury detected in sediments may come from drainages through cinnabar-rich deposits in the region. An increasing source of heavy metals is from malfunctioning heat exchangers; in one recent incident, enough copper was released from the tubing of the condenser of the nuclear power plant being constructed at Diablo Canyon on the California coast to kill large numbers of abalone (San Francisco Chronicle, January 24, 1975).

2. *Mill wastes*. The effluents of pulp mills consist of sulfate or sulfite liquors, indigestible wood particles (lignin) and other substances; often, the exact composition of the wastes is considered a proprietary secret, as it would betray the nature of the process. Steel mills may release cyanides, phenols and ammonia.

3. *Refinery effluent* usually consists of volatile hydrocarbons; crude oil is in a special category and may produce a catastrophic environmental mess in confined waters, although direct long-term damage is not easily measured. Some fractions such as diesel or heating oil act differently from the rest, moving into the bottom sediment and persisting in a condition hazardous to benthic life for many years.

4. *Pesticides, herbicides, and other agricultural runoff*. In some regions, as predicted for San Francisco Bay, there may be added the salinized agricultural runoff water from irrigated fields. A new addition to synthetic organics are artificial pheromones, substances that act like hormones and upset the natural sexual cycles of insects. Some of these may be dangerous to marine anthropods in very low concentrations, but they are only now being investigated.

5. *Chemical processing plant wastes*. Ours is an era of chemistry and the kinds of pollutants from our vast and complex industry are legion. They include acids, alcohols, all sorts of inorganic salts, and chemically inert materials that may interfere with filter feeding organisms. (The effect of taconite processing wastes could be very different from that in Lake Superior, for example.) Many chemicals are neutralized or rendered inert by interaction with seawater in more saline estuary conditions; others may become dangerous to life.

6. *Litter*. Bits of flotsam and jetsam have always been with us, but a new feature of our culture is the vast amount of material that is for the most part chemically inert, and reducible, if at all, by mechanical action. The surface of the oceans almost everywhere is littered with small pieces of plastic and the shores of estuaries are an unsightly mess of plastic receptacles, parts of toys, ballpoint pens, and sheets of plastic. Cans, bottles, and boxes degrade in time, but such things as the bridles for six packs of beverage may persist for years. None of this is pleasing to the eye and its effect on organisms, other

than physical entrapment or clogging the alimentary tract, is yet to be determined.

Obviously, it is impractical to monitor all the substances being released into the environment, especially when the presence or nature of some of them are unknown. One would like to have everyone assume, as good biologists should, that until proved harmless, a new substance should not be released in the environment for any purpose, and perhaps this is done on some other planet in some other galaxy, but not on the only planet we have.

OIL

So far, there have been few oil spills in estuaries; the spectacular Santa Barbara incident of 1969 occurred on the open coast. Fortunately, most of the spillage from the tanker collision at the mouth of San Francisco Bay on January 8, 1971, passed out of the bay, but major spill, and leakage from increased loading and unloading operations in busy ports is inevitable. Small leakages, in the order of perhaps several barrels a day, are considered a normal part of operations in an oil port, and such leakages are predicted for Port Valdez in Alaska when tankers will be loaded from the end of the Alaska pipeline. The example of what is happening in Bantry Bay on the west coast of Ireland is not reassuring. There have as yet been no adequate studies of the effects of such chronic pollution; most of our major ports have been subjected to this sort of thing for so long that no baseline is available from which to judge such effects. Port Valdez would be an ideal site for a baseline study, before the oil-loading facilities become operational.

Few harbors in North America are adequate for the massive new supertankers which may draw more than 60 feet when loaded; recently, a medium-sized (100,000 tons, dead weight) tanker was unloaded in San Francisco Bay at Richmond, but it was necessary to transfer three 15,000 tanker-loads from the large tanker before the ship could be moved to the dock. This sort of thing means more dangers from spillage with increased handling and, eventually, from an expensive fire along a commercial waterfront.

Unloading oil at refineries or pipelines is not the only source of potential pollution; many large power plants have their own oil docks, or plan to increase their facilities. For example, the Pacific Gas and Electric Company has applied for a permit from the Corps of Engineers to dredge 56,000 cubic yards from San Francisco Bay, to increase the capacity of its dock at Pittsburgh, some miles up the bay beyond Carquinez Strait. At the present time, tankers of 30,000 tons dead weight can be accommodated; the increased depth would make it possible for tankers of 70,000 tons dead weight to unload. One cannot of course afford to spill oil these days, and doubtless every precaution would be taken to prevent loss, but the public was not reassured to have the company attorney state that no expansion of dock facilities was planned for the Pittsburgh dock, at the same time the permit was being applied for. Such lack of communication within the company suggests operational difficulties could develop at the peril of the environment.

Puget Sound will be especially vulnerable to tanker accidents, because of the narrow passages to the proposed facilities near Bellingham and the density of maritime traffic. In anticipation of the potential difficulties in the region, a group of students and instructors at the University of Washington attempted to assess the problem and recommend procedures in the event of a major oil spill. The resulting document, "Oil on Puget Sound: an Interdisciplinary Study in Systems Engineering" (University of Washington Press, 1972), is a most instructive analysis of the problems, first of all of getting any accurate idea of the present magnitude of oil loss in Puget Sound and, most significantly, in revealing the lack of any coordinated plan or procedure to cope with the situation. These problems are concisely stated in the preface to this bulky contribution, and the statement can serve for other ports and estuaries in the United States as well:

> The objectives set forth at the beginning of the study were to define the oil spill problem in Puget Sound and to formulate a model for the solution of the problem. The study group discovered, as the study progressed, that identifying the sources and consequences of oil spills was a most time-consuming task. If solving a problem warrants a ten dollar reward, then definition of that problem should be worth at least one hundred dollars. At least, this was the sentiment of the group upon completion of their study. Thus, the primary efforts of the students were in collecting, analyzing, and evaluating data on Puget Sound and its related oil industry. It was only after completion of this tedious task that a meaningful solution could emerge.
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> * * * * *
>
> For the results of this study to evolve into an effective solution to the oil spill problem, the organizations involved, and the people within them, must consent willingly to change. Nothing could be worse than blindly instituting some legislation, technique, or procedure without fully understanding or accepting the overall impact of its activation. Too often, such fragmented actions are taken to obtain short run, narrow solutions to problems without evaluating the bigger picture.
>
> Historically, plans to cope with oil spills have emerged as the aftermath of disasters, or have been formulated in a vacuum, without considering the implication or consequence of such plans. Therefore, the most important message of this report is: *The environmental preser-*

> *vation of the Puget Sound region requires the coordinated effort of all responsible and capable parties, whether they represent society or industry.*
>
> (Vagners et al., 1972.)

It is to be hoped, as oil becomes more expensive and scarce, that economics will force more concern and less wastage if environmental concerns remain ineffective. Public concern was increased in the Puget Sound region by a series of articles in the Seattle Post Intelligencer during the last week of October 1974, which concluded with the question of the value of Puget Sound itself—is it worth the risk of a catastrophic oil spill, or do the "benefits" of massive oil commerce offset such a loss? Senator Magnuson, running for reelection, evidently sensed the public sentiment by taking the public position that the big tankers must be kept out of the inland waters of Puget Sound.

Attention was called during this controversy to the large oil spill from the tanker Metula in the Straits of Magellan; a more recent account suggests that the results of this spill, which occurred on August 9, 1974, may persist for years (Washington Post, Feb. 19, 1975). Because of the remoteness of the area and the expense, the government of Chile has been unable to make any attempt to clean up the 18 million gallons of oil. Obviously, these vast tankers should be kept to the open sea and broad, easily navigated harbors. Our estuaries do not meet these criteria.

SUMMARY

Since this review is essentially a summary of various factors degrading estuaries, a summary seems hardly necessary. If there is any conclusion to draw from this recital of estuarine ills, it is that much of what has happened to our estuaries is the result of our obsession with managing this most valuable of interface environments from the viewpoint of some specific use desired by man, or that planning panacea, "multiple purpose." Our recognition of environmental quality, of the need for maintaining "environmental integrity," suggests that our primary concern should be to manage estuaries on their own terms, as natural environments. Such management is inhibited by ecological ignorance or misunderstanding and, especially in most large estuaries, by conflicting jurisdictions and interests, by refusal of various local governmental agencies, as well as state and federal jurisdictions, to surrender sovereignty for the good of the natural system as a whole. All the mechanical (filling, dredging, diversion) and chemical pollution of our estuaries is exacerbated by our incomplete understanding of ecological processes and the confused idea that cost-benefit ratios and trade-offs are inteiligent management policies. Such concepts have no real meaning in the maintenance of natural conditions in the environment. It follows that most of our problems with estuaries (and of course with everything else) rise out of our own inadequacies and shortcomings, prompted by our anthropocentric concerns.

It is symptomatic of our present state of knowledge of estuarine management that Perkins (1974) in his text on the biology of estuaries, should devote more than 90 pages (including a list of 402 references) to biological effects of waste disposal, and six pages (with 10 references) to management.

One should not, however, stand too long at the wailing wall, but hope that we can learn to manage our estuaries without altering them for the worst. We have abundant information to help us in understanding many of our estuaries. What we need is respect for them as unique and significant environments; as I have stated in another context, we should develop an "estuarine conscience," a concern for estuaries on their own terms, not on ours, and get on with the task:

> The continued reliance upon consultants and other advisers to produce development plans, management studies, and proposals for monitoring programs are diverting funds from needed activities. The broad national policy is that estuaries must be preserved and maintained, and it is time that we began to do just that.
>
> (Hedgpeth, 1973.)

To put it more concisely, we have recognized that estuaries are places for life, not death, the places where the rivers should come safely to the sea.

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INTERACTIONS OF POLLUTANTS WITH THE USES OF ESTUARIES

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ABSTRACT

Twelve principal uses are made of estuaries, providing exceptional value to human interests. In the United States every one of these uses is expected to increase in the next 20 years above its present high level. At present, at least 16 major classes of pollutants are placed in estuaries, with effects that range from minor inconvenience to serious reduction in the usefulness of the system for other purposes. Some present pollutants have high potential for beneficial introduction if the quantity, site, and characteristics of the material are appropriate.

In this overview, the uses and pollutants are identified, the trend for each is noted, the principal deleterious effects of pollutants in coastal waters are summarized, and visual summaries are presented to suggest which of the uses may be affected by each class of pollutant.

INTRODUCTION

The purpose of this report is to identify the principal uses of estuaries and the significant pollutants entering estuaries in the United States, and to indicate which of the uses are likely to be affected by each pollutant. It is intended that this information be presented with both technical accuracy and ease of comprehension. Such a summary is necessarily limited to the broad national situation, and must be applied with care and local information to any estuary. The method for such local use will be suggested.

The International Oceanographic Commission (IOC) for the United Nations' Educational and Scientific Commission (UNESCO) defines pollution as: *Introduction by man, directly or indirectly, of substances into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, or hindrance to marine activities (including fishing), impairing the quality for use of seawater and reduction of amenities.* (Ketchum, 1972)

This definition will be used in subsequent discussion, with the interpretations that "substance" includes heat and that the term "oxygen demand" is employed as a short substitute for "substances which increase chemical or biological demand for oxygen."

This definition requires that one of the diverse uses that man makes of the aquatic area is or is likely to be deleteriously affected. Therefore, it seems reasonable and constructive to summarize the uses of the estuary and illustrate which of them might be damaged by each important class of polluting substances.

This presentation draws upon many of the other reports presented at this conference to help identify the principal present uses of estuaries, distinguish the most important pollutants at this time, and discuss some of the significant t ends in both uses and pollution.

THE PRINCIPAL USES OF ESTUARIES

The values which estuaries serve in relation to human activities have been summarized rather frequently in recent years, and it is helpful to review the listings developed. They are presented in Appendix A. It is apparent that these lists were prepared for various purposes and from diverse points of view. They have been employed to assist the preparation of a fresh listing which attempts to include all significant uses in the simplest set which is adequate and accurate.

Table 1 presents my listing of principal general uses of estuaries in the United States. Each of these is important to the people of the nation. However, subclasses of some of these uses merit specific attention, even in this national overview, since the effects of pollutants can be substantially different between the subclasses. For instance, recreational use for boating is not likely to be harmed directly by some of the chemical pollutants which may destroy fishing or hunting. Therefore, a limited number of subordinate categories has been chosen and included in Table 2, Principal Specific Uses.

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Table 1.—Principal general uses of estuaries

Commercial Shipping	Military Purposes
Shoreline Development	Research and Education
Recreation and Aesthetics	Climate Control
Mining	Biological Harvest
Electricity Generation	Preservation
Water Extraction	Waste Placement

Table 2.—Principal specific uses of estuaries

Commercial Shipping	Water Extraction
Shoreline Development	Military Purposes
A. For Residences	Research and Education
B. For Industry	Climate Control
C. For Recreation	Biological Harvest
Recreation and Aesthetics	A. Food
A. Boating	B. Industrial Materials
B. Swimming, Surfing, Sunning	Preservation
C. Hunting	A. Species
D. Fishing	B. Ecosystems
E. Aesthetic Enjoyment	C. Productivity
Mining	D. Other Features
A. Aggregates	Waste Placement
B. Oil and Gas	A. Human Wastes
Electricity Generation	B. Industrial Wastes

The intensity and value of each use varies widely for the 850 estuaries of the nation, and each system merits analysis and management on a specific and individual basis. For such analysis, these tables provide checklists to be culled and applied appropriately.

Each of the principal and specific uses is briefly discussed in the following pages, with notes on magnitude and trends if information is available. Extensive additional information is available in "The National Estuarine Pollution Study" (Federal Water Pollution Control Administration, 1969) and especially in other papers presented at this conference. "The National Estuary Study" of the Fish and Wildlife Service (1970), in its Appendix G, provided predictions (which will be called NES forecasts) of uses for selected estuaries including Penobscot Bay, Delaware Bay, Charleston Harbor, Tampa Bay, Galveston Bay, Newport Bay (Cal.), San Francisco Bay, Yaquina Bay, Puget Sound, and Cook Inlet. These and other projections are noted below.

Commercial Shipping

The estuaries include every port in the nation, since offshore ports have not yet been developed. Therefore, all surface import and export, as well as all coastal and local traffic by ships, tankers, and barges, involve estuaries. The great coastal cities were sited as they are because of estuarine shipping, and continue to be dependent on such transport. Commercial shipping, involving many kinds of vessels, increased substantially in recent decades to a level of 1.6 billion tons in 1972, and is projected to continue that trend in the foreseeable future (Langlois, 1975). The NES forecasts predict increased commercial shipping in all eight case study estuaries (Fish and Wildlife Service, 1970).

Shoreline Development

Construction and other engineering of the shallow floor, shoreline, and adjacent land mass have been intensive around every coastal city, and extensive as thousands of miles of estuarine edge have been modified for residential and recreational use. The population of the United States is rapidly shifting to the coastal area with resultant intensification of such development (Belcher, 1975). Exceptional growth in populations is expected to continue in coastal regions (Belcher, 1975), so that such alterations are likely to increase.

Conservation has been apparent recently in managing wetland conversion and, indeed, all modifications of estuarine edges. This backlash to the almost ungoverned development of such areas is presently slowing the changes. The uncertainties of economic probabilities and legislative predilection preclude useful forecasting of specific trends.

For Residences

These include permanent homes, part-time cottages, and campsites. They frequently involve alterations from grading and construction and the use of bulkheads and piers for land protection and recreation. The quality of sites for use for residences usually depends on the aesthetic quality of the estuary and surrounding lands, and secondarily on potentials for such activities as fishing and boating. Belcher's summary of recent trends for the eastern seaboard suggests that residential use of estuarine edges is likely to be increased by the shift of population, by more leisure, by early retirement, by the growth of commuting, by the trend toward more dwelling units per family group, and by the quest for a new quality of life with more contact with nature. In all of eight specific estuaries, increased residential development is expected (Fish and Wildlife Service, 1970).

For Industry

This development covers waterfront facilities (deepwater, piers, intake and effluent structures,

bulkheads, fills and specialized structures) and on-land buildings, transportation systems, utilities, and other appurtenances. No statistical summary of recent and prospective trends is available to me, but future use for these purposes seems likely to be substantially affected by nationwide efforts to zone coastal activities. NES forecasts project greater industrial development in all of the eight example estuaries studied (Fish and Wildlife Service, 1970).

FOR RECREATION

Public and private parks and beaches are included here, as well as camping areas, facilities to support boating, and other installations. The use of estuarine shores and waters for recreation is very large and expected to grow (Kalter, 1975), and the development of associated facilities is expected to follow parallel trends. Kalter summarizes from Adams et al., 1973, relevant data on recreational activity and expected demand in all of the BEA areas adjacent to estuarine zones. This totaled over 500 million activity days in 1972, not all on estuaries. Every activity (boating, swimming, nature walks, fishing, water skiing) is expected to increase from 1972 to 1975 for each of the 37 estuarine areas documented in the 1972 survey. Kalter notes that the demand for facilities is unlikely to vary much from the demand forecast based on population and that facility supply is the balance wheel to the demand. Significant variation is apparent by region and by types of recreation, and change in preference is expected. The national trend of development for this use is strongly predicted. Recreation also is expected to increase in each of the eight case study estuaries in NES forecasts.

Recreation and Aesthetics

Use of estuaries for personal pleasure and refreshment takes many forms in the almost infinite variety of specific situations which exist in, on, and around such bays and waterways. Predictions for continued increases in population movement to, and personal use of, estuarine areas provide similar prediction of greater recreational and aesthetic use. Brief additional comment on each selected subclass of use is appropriate.

BOATING

This category is widely diversified, from dinghys and paddleboats through canoes, rowboats, kayaks, pirogues, small to large outboards, sailing vessels, houseboats, and barges, to yachts from modest to palatial. Kalter reports that 49,045,000 days involved boating in the U.S. BEA areas adjacent to estuarine zones in 1972, and that every area is expected to increase by 1978, with an average of 17 percent. All eight case estuaries are predicted to undergo increased boating (Fish and Wildlife Service, 1970).

SWIMMING, SURFING, SUNNING

The variety of pleasant activities along the beach and in or on water needs no definition. This combination of activities is, according to Kalter, the largest recreational activity in the BEA areas adjacent to estuarine zones, involving at least 250,000,000 person days in 1972. By 1978, increases of 12 percent for swimming and 14 percent for skiing are forecast by Adams (1973).

HUNTING

Waterfowl, shorebirds, game mammals, and reptiles are all hunted for recreation. Irby (1972) notes the dependence of many of these on the estuary and their presence in many different estuarine habitats. Bird hunting can involve use of several estuaries at once since many species are highly migratory and may reproduce, feed and rest on different bodies of water—all of which are necessary. No data are at hand on the extent of use of estuaries for hunting, on recent trends, or on future probabilities.

FISHING

Angling, with gear ranging from the simplest hook and line to the complex rigs used for giant carnivores, is popular on all coasts. Clark (1975) summarizes data from a 1970 survey by the National Marine Fisheries Service to note that 10,000,000 coastal anglers caught 350,000,000 fish along the coasts and 468,000,000 in estuaries—which provide essential support for many or most of the coastal catch. From 1960–1970, participants increased by 50 percent. Additional data provided by Kalter describe 110,000,000 fishing days in 1972 in BEA zones adjacent to estuaries and project a 9 percent increase by 1978. NES forecasts predict greater fishing in all eight sample estuaries (Fish and Wildlife, 1970). Bollman (1975) expects increase in value of the fish caught, of the social activity, and of related goods and services. As with commercial harvests discussed below, it is important to note that estuaries are essential breeding and nursery grounds for most of the coastal

species and provide necessary migratory pathways for a wide variety of fish.

AESTHETIC ENJOYMENT

Visual pleasure from water and shores; lazing in the environs of estuary; observing birds, plants and animals; and a great variety of other uses engaging the senses and emotions are widely enjoyed. Counts and measurements of such use are difficult to obtain—and not easily separated from other recreational uses. Kalter provides one index, reporting that nature walks involved over 62,000,000 activity days in 1972 and may increase 14 percent by 1978. As for other uses, fuel expense or shortage may enhance such usage for those nearby, and reduce it for those who must travel.

Mining

Sand, gravel, oil, gas, shell, and commercially useful quantities of various chemicals occur under estuaries as under many other surfaces on the earth. Except for such biogenic deposits as shells of estuarine molluses or of coral, their presence has no relationship to the existence of the estuaries, with which they are in accidental coincidence. The uses of such materials have varied, and probably will vary, as different materials become useful, as techniques for locating and extracting minable substances are improved and as more easily accessible sources on land become partially or completely exhausted. Estuarine mining is now relatively limited, and Riggs (1975) points out that our knowledge of the potentials of both estuaries and the continental shelves is presently only superficial.

AGGREGATES

For the purpose of this summary, and at some variance with geological terminology, this includes surface and near-surface sediments, gravels, sands, clays, shells, and chemicals. Biggs describes the huge American demand for some of the materials and the difficulties of making reliable estimates of estuarine production, and notes that increased populations near estuaries are highly likely to increase demand for the exploitation of useful deposits. Shell deposits by oysters, brackish-water clams, and other species have many uses (including that of cultch to assist the production of more shellfish), but some of the massive deposits are apparently showing depletion (Biggs, 1975; Espey, 1975). Special purpose clay mining and extraction of minerals, including precious metals, are known to exist and mining is likely to increase. Salt, sulfur, and potash minerals are primarily associated with evaporite deposits, and Biggs considers the increased extraction of these to be highly probable. Mining is expected to grow in six of eight case study estuaries, and to remain at about the same level in Charleston Harbor and Yaquina Bay (NES forecasts).

OIL AND GAS

Extraction of these materials within estuarine areas has been occurring in Louisiana, Texas, and Alaska, at least. No data are available on present and future trends.

Electricity Generation

Direct use of estuarine water for condenser cooling water, the most-discussed use of estuaries in the generation of electricity, was generally avoided as long as utilities could obtain fresh water and eliminate the problems associated with use of saline or brackish water.

Production of electricity may utilize estuaries in several different ways. The most direct use is for condenser cooling in steam electric stations. Water may constantly flow through the system or be withdrawn to make up evaporative losses in cooling towers. The dependence of large nuclear plants on estuaries as the only feasible means of transporting massive containment vessels and other large components sometimes controls the siting of such plants.

Such uses are relatively recent in coastal bays, and no summary of present estuarine use has been seen. Because populations and industrial activities are growing in coastal areas, demand is expected to increase and there have been predictions of as many as 10 large nuclear plants in upper Chesapeake Bay and its tributaries, for instance. Mihursky (1975) notes the recent regulations which may substantially affect the direct usage that such systems will make of estuaries. No simple prediction appears feasible at this time.

Water Extraction

The salt content of most estuarine waters seriously hampers use for drinking water, agricultural irrigation, industrial processing, and other purposes common for fresh water, although all of these occur at some sites, especially in fresh or nearly fresh tidal waters. Such use as that of a heat transfer medium in generating electricity or some other industrial

processes is not an extraction but a borrow, since the total quantity is usually returned near the intake.

The principal extractive use of water is from the total watershed of estuaries. Withdrawal may occur for inter-basin transfer (Delaware to the Hudson, Sacramento Valley to Los Angeles, and so on), for irrigation, or for other uses which permanently remove water and may drastically affect the estuary. Uses which involve substantial alteration of the pattern of flow releases into the estuary (damming for hydroelectric generation, water supply, recreation, flood control) are not extractive but may also have important estuarine consequences. These differ from the extensive borrow-and-return pattern of most domestic and industrial use, which has little estuarine effect.

No data are available for estimating present extractions of estuarine water nor for predicting trends.

Military Purposes

These include transportation, firing and ordnance ranges, research on vessels and equipment, filling for air strips and other land use, storage of vessels, vessel construction and maintenance, coastal patrol and its support, and education in naval operations, flying, and related fields. No summary has been seen of the present extent of these uses, although they are obviously large in some bays and estuaries. Prediction is impossible, since extended periods of peace may bring reduction in some of these activities as being unnecessary or inappropriate for estuaries—and escalation toward war would make other considerations relatively trivial.

Research and Education

Research is conducted in estuaries to solve the problems which occur and to broaden understanding. Since estuaries have many problems which are increasingly recognized to be important, there has been rapid increase in the number of projects related to fisheries, waste management, water quality, and the social, economic and legal aspects of estuarine use. In addition, the diversity and dynamicism of the geological, physical, chemical, and biological components of estuarine systems have also attracted growing use as wild laboratories.

Similarly, estuaries are highly used in training students, both in livelihood (fishing, recreational boating, maritime skills, and so forth) and fundamental sciences and arts. Marine and estuarine biology has been the most popular field, and a survey of scientific personnel involved with the eastern estuarine environment indicates that research interests among 644 respondents to 1,200 queries were overwhelmingly biological in 1972 (Kerby and McErlean, 1972). All of the many other fields listed lagged far behind, confirming impressions at conferences on coastal topics.

Recent trends have been for increased research and teaching. Large estuarine research societies now exist, with the umbrella Estuarine Research Federation having about 1,200 members in constituent societies in New England, Middle Atlantic, South Atlantic, and gulf coast regions. Several similar groups have been formed on the west coast. Estuaries will be used extensively for these purposes, but future trends are difficult to predict because most financial support is from state and federal funding, which in itself is presently unpredictable. "The National Estuary Study" predicted increased use for research and education of seven of eight selected estuaries, with continuation at the same level in Galveston Bay (Fish and Wildlife Service, 1970).

Climate Control

Modification of climate is perhaps the most extensive, least measurable, and least priceable use of estuaries. As compared with land masses, they moderate summer and winter temperatures, lag spring and fall temperature transitions, and increase humidity. These substantially affect uses for residential, recreational, industrial, and aesthetic purposes, but the value of such effects is obviously complex and elusive. The trend of this use, if indeed that word is appropriate, is proportionate to the activities listed above. Since they are expected to grow, so too will the importance of climate modification by estuaries.

Biological Harvest

Since estuaries have higher natural rates of production of organic materials than almost any other biological system (Teal and Teal, 1969), large biological populations exist and have been harvested throughout the world. Most of the harvest is achieved by hunting techniques, capturing the yield with little or no investment in cultivation, although management through public agencies and by private efforts exists and may increase. Harvest for food and harvest for industrial materials are not significantly different, despite the different distribution of the products—and consequent difference in the ultimate users. These two subclasses of the biological harvest will be treated together in this brief discussion.

The catch of estuary-dependent species was worth about $660 million at dockside in 1973, about 73 percent of the total commercial fish landings value of $900 million for the United States (Tihansky and Meade, 1975). All of the principal species are useful for food except menhaden, although some of the food species also yield industrial products (bait, meal, shell, and so on). Menhaden, the great industrial species which provides meal, oil, and many chemical products, had a 1973 landing of 1.9 billion pounds, valued at $73 million at dockside (Broadhead, 1975). Both food and industrial species increase at least severalfold in value as they move through processing, distribution, and sales to reach the consumer. Even at dockside values, Bollman (1975) notes that the capital required to produce $660 million would, at 5 percent yield, be about $13.2 billion dollars, an approximation of the value of estuarine fisheries—and of this use of estuaries.

Prediction of use trends for estuarine biological resources is exceptionally difficult. In the "National Estuary Study," increased fisheries were predicted for all of the eight case study estuaries, but this may have mixed estimates of demand with estimates of yield. Broadhead (1975) has stressed the instability of marine populations and the complexity of the factors which may affect abundance. It is not possible to forecast the supply, although demand for both food and industrial harvest will increase.

Preservation

Estuaries contain many biological forms, assemblages, environments, and other features which merit preservation. These have been noted and extensively considered in the volume "Marine and Estuarine Sanctuaries, the Proceedings of the National Workshop on Sanctuaries" (Virginia Institute of Marine Science, 1975). Preservation may be needed to assure the continued existence of a species or system, to protect such a component for future availability, to guarantee the productivity of all or part of an estuarine system or to preserve a unique physical, geological, chemical, or biological feature.

Partial preservation now occurs in various wildlife refuges, sanctuaries, parks, and preserves, but there is no national summary of the quality or quantity of such protection. Those participating in EPA's Conference on Estuary Pollution Control vigorously proposed substantial increase in this use of some parts of the national estuarine complex, and provided detailed guidance for such preservation. Both the Coastal Zone Management Act of 1972 (P.L. 92-583) and the Marine Protection, Research and Sanctuaries Act of 1971 (P.L. 92-532) contain authorization and encouragement for increased preservation in estuaries, so that such use may be expected to grow.

Waste Placement

Waste placement is used with intentional avoidance of the comforting term "waste disposal" since even slight critical thought proves that most of our placement of waste materials has not disposed of them—merely transferred them from one site to another. Estuaries have always received substantial quantities of the materials humans wish to dispose of because (1) estuaries lie in the basin-catching position for all land drainage; (2) population clusters along the coast; (3) the chemistry, geochemistry, and dynamics of estuaries provide large capacities for some wastes without harm, or at least visible harm, to other users; and (4) the magnitude and extent of possible damage from wastes was not even partially known until recent decades. The cheapness, convenience, and capacity of estuaries for receiving wastes favor their use within appropriate limits—the extraordinary values, dispersive nature, and relative fragility of the biological systems require conservative use for such purpose.

Human Wastes

At source, human wastes are already complex. Undigested foods and liquid products of metabolism, neither of which is chemically simple, are quickly mixed with shower and bath water, kitchen wastes, washings, and anything else put in the toilet or sink. In systems for sewage collection and treatment, these are frequently combined with industrial wastes and, intermittently, with surface runoff from storms. Even after some degree of treatment, such wastes are usually composed of many materials. For instance, the discharge from the Hyperion and White Point outfalls on the west coast contains more than 20 components to a level of a ton or more discharged per day to the receiving waters. The specific composition of the discharge varies principally with the sources of waste and the kind of treatment, generally but imprecisely described as none, primary, secondary, or tertiary (advanced). No operating plant completely removes all potential pollutants from domestic wastewater except on an experimental or pilot scale.

The magnitude of such wastes is difficult to estimate. As an example, a recent inventory of sewage treatment plants for Chesapeake Bay (Brush, 1974) identified 243 such plants, of which 35 provided primary treatment and 208 were secondary. The total effluent was estimated to be 2.8 percent of

Table 3.—Generated municipal wastes

	1960	1970	1980	Increase 1970–1980
Wastewater, billion gallons	1,612	1,902	2,131	229 or 12%
Standard BOD, millions of pounds	2,230	2,632	2,974	342 or 13%
Settleable and suspended solids, millions of pounds	2,686	3,171	3,551	380 or 12%

the average freshwater flow into the bay. Without similar data from other estuaries, national summation is impossible, but the use is obviously a very large one.

Trends will be affected by the developing pressures from population increase and the changing constraints through regulation. The first of these has been briefly described above, and the very great changes in national regulations have been summarized by Hargis (1975). "The National Estuarine Pollution Study" (1969) quoted (P IV-334) from a FWPCA publication "The Cost of Clean Water" that the national estuarine population would generate the following quantities of several components in the areas served by sewers.

No certain prediction is possible, because economic, political and environmental efforts are all likely to be intense. The outcome cannot be foreseen.

Industrial Wastes

The composition of unwanted materials from commercial activity is as variable as the industry. (See "The National Estuarine Pollution Study," 1969, pp. IV-386 to IV-389, Volume II, for a catalog of such wastes, their characteristics, and the distribution among the states.) Through most of the industrial period in this country, industries were permitted to take full advantage of the economy of placing wastes in nearby waterways as long as they did not endanger human health or cause quite obvious damage. Change in public knowledge and concern in recent decades has brought all new industry, and much old, under considerable control in this regard. As a result of this transition, waste placement has been drastically reduced, although there are residual uses in the forms of (a) contaminated deposits from previous activities, (b) uncorrected violations of regulations, and (c) transport of wastes short distances to the oceanic water as a means of disposal.

The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) direct use of "best available" control technology by July of 1977, "best achievable" by July of 1983, and states a national goal of eliminating all pollutant discharge.

THE REAL WORLD OF USES

Rarely, if ever, is an estuary utilized significantly for only one of the uses noted above. Even primitive populations of low technological capability are likely to fish, use boats, place wastes, and recreate in such waters. This, then, is the simplest form of multiple use, and the most complex form occurs in the harbors of industrialized cultures with large populations, where every listed use may be occurring at once. The problem lies in the fact that almost every use can become so large that it impinges upon other uses and users.

Several interesting and potentially useful concepts for managing uses of estuaries have received recent attention and may become incorporated in coastal zone management. One may be called an exclusion concept, which dictates that the exceptionally valuable shoreline will be reserved for those uses which are genuinely dependent on such siting—and excludes those which are not. For instance, docks, swimming beaches, and large marine railways can only exist at the edge of water. Processing plants (even for seafood), power generating stations, and oil refineries can frequently be sited as well, or better, away from the estuary. Such siting may become mandatory. Another concept receiving present currency is that of clustering of uses, an intense form of zoning. If industrial activities are concentrated, the argument runs, efficiencies are possible in providing utilities, handling wastes, and arranging transportation, as well as in surveillance and enforcement. With clusters, more of the total estuarine shoreline is left without problems of such use. These concepts, and many additional ideas, seem likely to receive increased attention as the task of balancing uses, the focal thrust of the Coastal Zone Management Act of 1972 (P.L. 92-583), is implemented.

It is appropriate to note, in this discussion of the interactions of pollutants with the uses of estuaries, the obvious but very important fact that use is usually the source of pollution. Most, but not all, of the listed uses have this potential. Change in usage or change in the regulation of pollution can have major effects on each other.

The large task is that of achieving, through sufficient knowledge and wise government, the optimal balancing of multiple uses of estuaries so that they serve the public interest most effectively. To achieve this, all human activities must be constrained so as to remain within the inherent capacities of the estu-

Table 4.—Principal pollutants of estuaries

Pathogens	Brine
Sediments	Toxic Inorganics
Solid Wastes	Toxic Organics
Color Sources	Petroleum
Odor/Taste Sources	Nutrients
Floatables	Radioactivity
Heat	Oxygen Demand
Freshwater	Acids and Bases

arine system—lest they destroy the system and its uses.

THE PRINCIPAL POLLUTANTS OF ESTUARIES

Introductions by human activities which can be damaging in estuaries have been cataloged several times, and some recent lists are provided in Appendix B. Taking advantage of these summaries, a new listing of 16 pollutants has been prepared, again attempting to include all significant introductions in the simplest set which is both accurate and adequate (Table 4). Each of these is defined or described, and references are provided to selected papers which contain information on the quantity and probable future trend of each.

Pathogens

Living organisms which can cause pathology or sickness in either the animals and plants within the estuary or in humans who eat or contact materials taken from the water include a wide variety of bacteria, protozoa, viruses, and fungi. Human pathogens are frequently abundant in sewage, but may enter the water from other waste disposal or from accidental spills. The pathogens of aquatic species are often introduced with transplanted organisms, and are often indirectly affected by environmental alterations such as salinity increase or decrease. See: Colwell, 1975; Ketchum, Ed., 1972; McEwen, 1972; "National Estuarine Pollution Study," 1969; Sindermann, 1972.

Sediments

Inorganic particulate materials ranging in size from clays and silts up to at least sands may occur in many forms, from essentially single-size loads to extremely complex mixtures of particles with loose and firm aggregates containing many materials. Estuaries are inherently sediment traps, but the effects of man's activities through practices in forest clearing and agriculture, surface alterations in urbanization, mining activites, channelization, poor sediment control during construction of roads and other facilities, excessive enrichment, solid waste placement, and dredging and spoil placement have massively increased the rate and quantity of sediment input, deposit, resuspension, and redistribution in many of the nation's estuaries. Storage reservoirs and improved land management practices have sometimes effectively reduced sediment input. See: Boyd et al, 1972; Carpenter, 1975; Committee on Water Quality Criteria, 1969; Hedgpeth, 1975; Hood, 1975; Lee, 1975; "National Estuarine Pollution Study," 1969; Schubel, 1975.

Solid Wastes

Accumulated unused solid wastes are presenting one of the serious problems of all urban, and many suburban, areas. Domestic materials, agricultural wastes, and, especially, industrial unused products are involved. Estuarine placement has been widely used as one of the alternatives, with placement ranging from dumps in the marsh and edge of the river to ship transport to deeper water. The composition of such materials defies single description, and the effects include those of sediments, toxicants and many other pollutants. See: Committee on Water Quality Criteria, 1972; Feibusch, 1975; Gross, 1969; Hood, 1975; Smith, 1975.

Color Sources

Natural sources of color in estuarine waters include leachates from marshes, swamps, and other vegetative areas, suspended particles, and blooms of plankton. Human effects on color are most likely from industrial effluents or accidental spills. Color is not toxic, but affects the quality and quantity of light penetration and availability, and the material causing color may have additional effects.

Odor/Taste Sources

Many materials can affect the odor or flavor of edible (to humans) estuarine products or the aesthetic quality of the estuarine environment. They are primarily organic, and the most common are oils and petroleum products. Little is known about the effects of various materials on the edibility of estuarine species by other species, although it is reasonable to suspect that it occurs and may be important. The effect on human seafoods is economic, since the presence of offensive odor or taste usually prevents

eating sufficient quantity to cause illness. See: "The National Estuarine Pollution Study," 1969.

Floatables

Low-density materials on the surface may be in the form of slicks, globs, wood and fibrous organic material, undigested plastics of many types, rubber goods, sealed bottles or cans and many other substances which are either inherently light or capable of holding gases. They occur on the surface and usually move to the shoreline. See: Pearson, 1975.

Heat

Heat is introduced into the estuary from condenser cooling in power plants, cooling by other industry, and in relatively small amounts incidentally with other waste discharges. After initial warming, the receiving waters act essentially as a transfer medium, conveying virtually all introduced heat to the atmosphere. This release may involve extremely large estuarine areas, because of dispersion by tidal flow and mixing processes. See: Blake, 1975; Committee on Water Quality Criteria, 1972; Clark and Brownell, 1973; Cronin, 1975; Hedgpeth, 1975; Jensen 1975; Mihursky, 1975; Smith, 1975; Water Resources Criteria, 1972.

Fresh Water

Damaging introductions of fresh water resulting from man's activities can result from opening of spillways and diversion channels, release of large volumes of low salinity effluent in water of higher salinity, and land use practices which permit flashier runoff than would have occurred under natural regimes. See: Cronin, 1967; Smith, 1975.

Brine

Salt in detrimental concentration may be introduced as true brines from industrial activity or from blowdown residues in cooling towers. It may also be added in more dilute form observable as salinity increase above that which would have occurred without human causes. This can be caused by diversion of freshwater from the watershed for consumptive uses like inter-basin transfer, irrigation, or evaporative cooling towers; by deepening of channels; by up-stream release of condenser cooling water; and by other mechanisms. See: Hedgpeth, 1975; Schubel and Meade, 1975; Smith, 1975.

Toxic Inorganics

Although every inorganic element or compound can be toxic at some level of concentration and exposure, attention is usually most appropriate for those of exceptionally high toxicity or probability of release. Thirty-five to 40 elements and a much larger number of compounds are known to be potential serious pollutants. These exist in industrial effluents, domestic waste treatment effluents, biocides (especially as the result of chlorination), drainage from mines or quarries, and many other sources. Especially thorough summary has been presented by the Committee on Water Quality Criteria, 1972. See: Blus et al. 1975; Committee on Water Quality Criteria, 1972; Hedgpeth, 1975; Hood, 1975; Ketchum, Ed., 1972; Middaugh and Davis, 1975; "National Estuarine Pollution Survey," 1969; Smith, 1975.

Toxic Organics

Most of the especially toxic organic compounds turned loose in estuaries are synthetic compounds, and the most serious are those which are highly persistent. They arise primarily from the wide range and large quantities of biocides employed on land (fungicides, herbicides, insecticides, rodenticides) but also from additional halogenated hydrocarbons, petroleum, and industrial chemicals. The nature and experimental toxicity of these creations of man have been detailed by the Committee on Water Quality Criteria, 1969. See: Blus et al. 1975; Butler, 1975; Committee on Water Quality Criteria, 1969; Hedgpeth, 1975; Ketchum, Ed., 1972; Lincer, 1975; Smith, 1975; Walsh, 1972.

Petroleum

Petroleum and its complex components are principally organic but the extraction, transportation, handling, refining, and distribution of these fossil energy sources have created a distinctive set of problems in pollution. Since estuaries are the waters of entry, and petroleum pollution is highly associated with transporting, handling, and refining, considerable concern exists and will continue. See: Blus et al. 1975; Brown, 1975; Committee on Water Quality Criteria, 1972; Farrington, 1975; Hedgpeth, 1975; Hood, 1975; Ketchum, Ed., 1975.

Nutrients

Nutrients are the chemical raw materials which are essential for biological processes. These enhance

productivity in appropriate quantities but can seriously disrupt the estuarine ecosystem through excessive enrichment. Nitrogen, phosphorous, and carbon are the most noted specific elements, but less abundant elements and compounds can be significant. Polluting quantities can be introduced from sewage effluent, runoff from cleared or agricultural land, detergents, street runoff, and industrial wastes. As eutrophication occurs with increasing frequency and at additional locations, many consider these additions to present one of the most serious threats to best use of estuaries. See: Champ, 1975; Committee on Water Quality Criteria, 1972; Hobbie and Copeland, 1975; Ketchum, Ed., 1972; Pearson, 1975; Smith, 1975.

Radioactivity

Radioactive elements and compounds can enter the estuary from fallout from atmospheric burden, from testing of weapons and other uses, release of wastes from nuclear power plants and other users of such fuels, drainage of mines, accidental spillage in hospitals, and with wastes from reprocessing plants and some industries. Because of increased introduction, longevity of emission, and the knowledge that it can cause somatic and genetic damage in estuarine biota and possibly in humans, this relatively new pollutant is of national significance. See: Committee on Water Quality Criteria, 1972; Ketchum, Ed., 1972; National Academy of Sciences-National Research Council, 1971.

Oxygen Demand

Some additions can create additional demand for the finite quantity of oxygen in estuarine water. Sewage sludge, wood wastes (pulp, bark, chips), sediments stirred during dredging operations, and the secondary effects of excessive enrichment can all contribute to this demand. Freshwater management practices which increase vertical stratification during periods of high temperature will enlarge the area and volume of oxygen depletion in some estuaries. See: Committee on Water Quality Criteria, 1972; Hood, 1975; Ketchum, Ed., 1975; Pearson, 1975.

Acids and Bases

A complex carbon dioxide-bicarbonate-carbonate system buffers estuarine waters to help stabilize them against change from the addition of acidic or basic chemicals. The buffering capacity can, however, be exceeded by large additions, and thus would dangerously alter the environment of the biota, which cannot survive much change of this kind. In addition, the toxicity of most other pollutants increases under such circumstances. Acids or bases might reach the estuary from mine drainage, accidental spills, or industrial wastes. See: Committee on Water Quality Critieria, 1972.

THE EFFECTS OF POLLUTANTS*

The introduction of a chemical compound or a change in the physical environment may affect a natural marine ecosystem in many ways. In coastal waters undisturbed for long periods of time, the ecosystem has adjusted to the existing conditions. The system is productive, species are diverse, the biomass is high, and the flow of energy is comparatively efficient. The addition of pollutants to such a system might:

- reduce the input of solar energy into the ecosystem;
- increase the input of organic matter and nutrients which might stimulate the growth of undesirable species;
- reduce the availability of nutrients by increased sorption and sedimentation;
- create intolerable physical extremes for some organisms, as by the addition of heat;
- kill or reduce the success of individual organisms, as by lethal toxicity or crippling with oil;
- eliminate species by adding a toxic material or making an essential element unavailable;
- interfere with the flow of energy from species to species, as by a chemical that interferes with feeding behavior;
- reduce species diversity in the system;
- interfere with regenerative cycling by decomposers;
- decrease biomass by reduction of abundant species or disruption of the processes of ecosystems;
- increase biomass by removing important consumers, allowing runaway production of other species.

All of these may involve changes in production and lowered human usefulness of the system. These are examples; additional effects can occur. The specific impacts of pollution at a site can be determined only through long-term study of that portion of the ocean and the changes that occur.

* Verbatim from Committee on Water Quality Criteria, 1972, pp. 219-220.

VISUAL SUMMARY OF THE INTERACTIONS BETWEEN POLLUTANTS AND USES

Matrix charts have been prepared to suggest which of the uses are likely to be significantly affected by each pollutant (Figures 1 and 2). A simple set of symbols was selected, so that:

Black: Danger, this pollutant can have serious effects on that use.

Hatched: Caution, this pollutant may in some circumstances reduce that use.

Grey: This pollutant can be beneficial to that use in favorable circumstances.

Blank: No substantial effect is known to occur.

As with all efforts to reduce massive complexity to an unqualified simple summary, the viewer shares some of the responsibility for preventing mis- or over-interpretation. The following qualifying comments may help:

1. *The selection of signals is subjective,* not quantitative. It is based on about 35 years of scientific experience with estuarine pollution, participation in several of the panels cited, and the advantage of excellent reports prepared by many expert specialists.

2. *The time scale is difficult to handle.* As regulations are changed, or enforcement is modified, or new knowledge emerges, the real threat from a pollutant is altered. So, too, may the importance of a use vary with time. These estimates apply to 1975.

3. *Each estuary is unique.* This matrix intentionally stresses the most likely interaction among the 850 or more such systems in the nation, but each case can be effectively understood only on its own terms. Perhaps the matrix can best be posed as a series of questions for each estuary—"Is this pollutant reasonably likely to have the suggested effect on that use? If not, what is the real local relationship?" At least, a useful set of questions may be summarized in the matrices.

In most cases, it is probably easy to comprehend the opinion of the author, but one set of symbols requires explanation—those under the use of Research and Education. While the presence of a pollutant offers opportunity for study and for teaching, that interaction was not chosen for emphasis. Rather, the symbol indicates how the pollutant is expected to affect research and education on the basic nature, components, processes, and systems of estuaries—and many of the pollutants might either interfere with or substantially enhance such research and the effective education of students.

These matrices may have several uses. They suggest which pollutants are potential threats to the fewest and to the most uses, and which face the largest and smallest number of probable sources of damage—and all of the intermediate probabilities. Thus, they may help in identifying the pollutants of highest priority for control in national, regional, state, or local programs. In any one estuarine system, selection of the uses most valuable to, or preferred by, the people of the region can be followed by preliminary identification of the most probable sources of destruction for those uses. Such a preliminary identification from these matrices would, of course, be but the first step in constructive local efforts to assure good balance. One of their most stimulating aspects is the display of many potentials for constructive use of possible pollutants—of conversion of problem materials into positive resources. If preparation of these summaries facilitates that necessary process, value will have been achieved.

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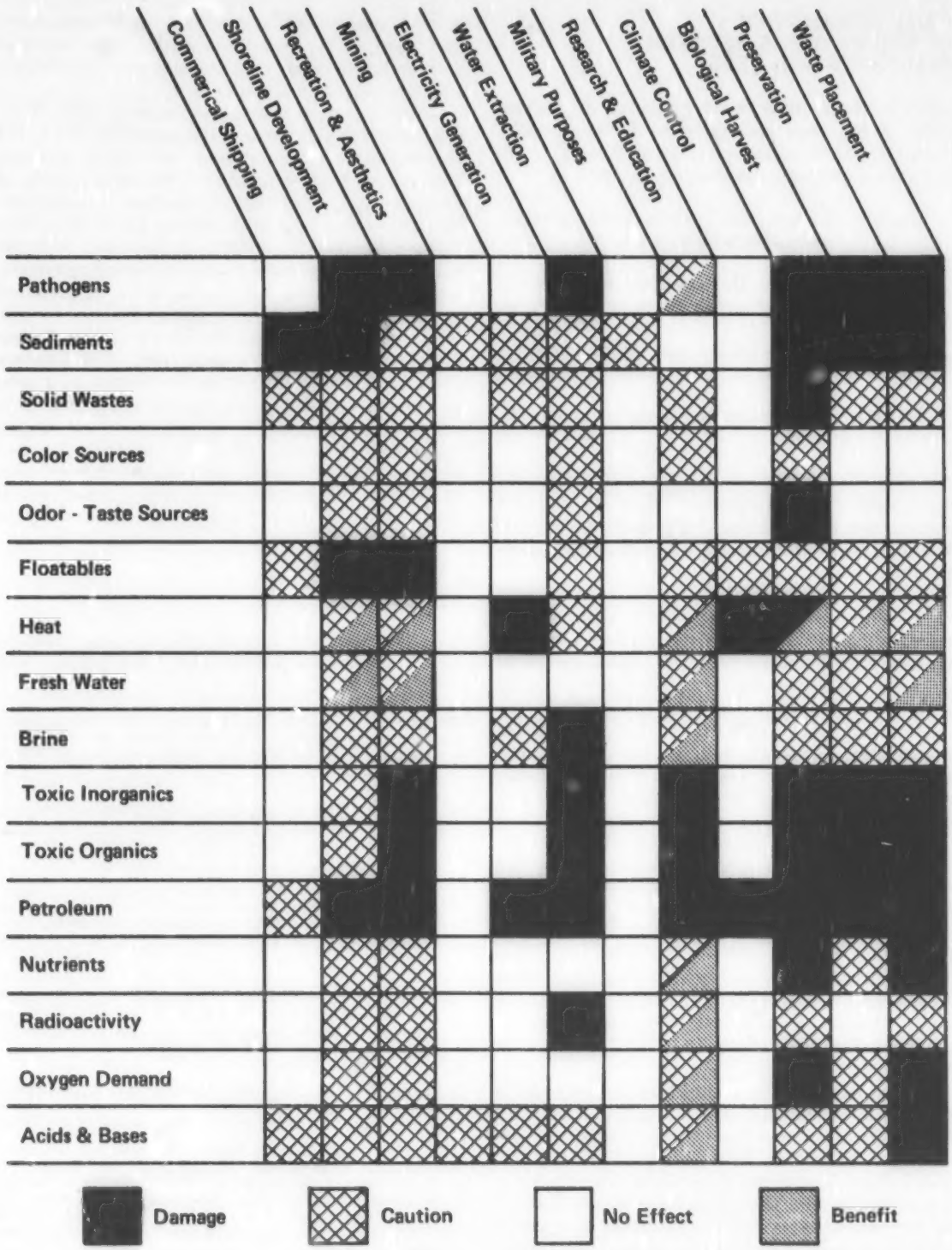

FIGURE 1.—Probable effects of pollutants.

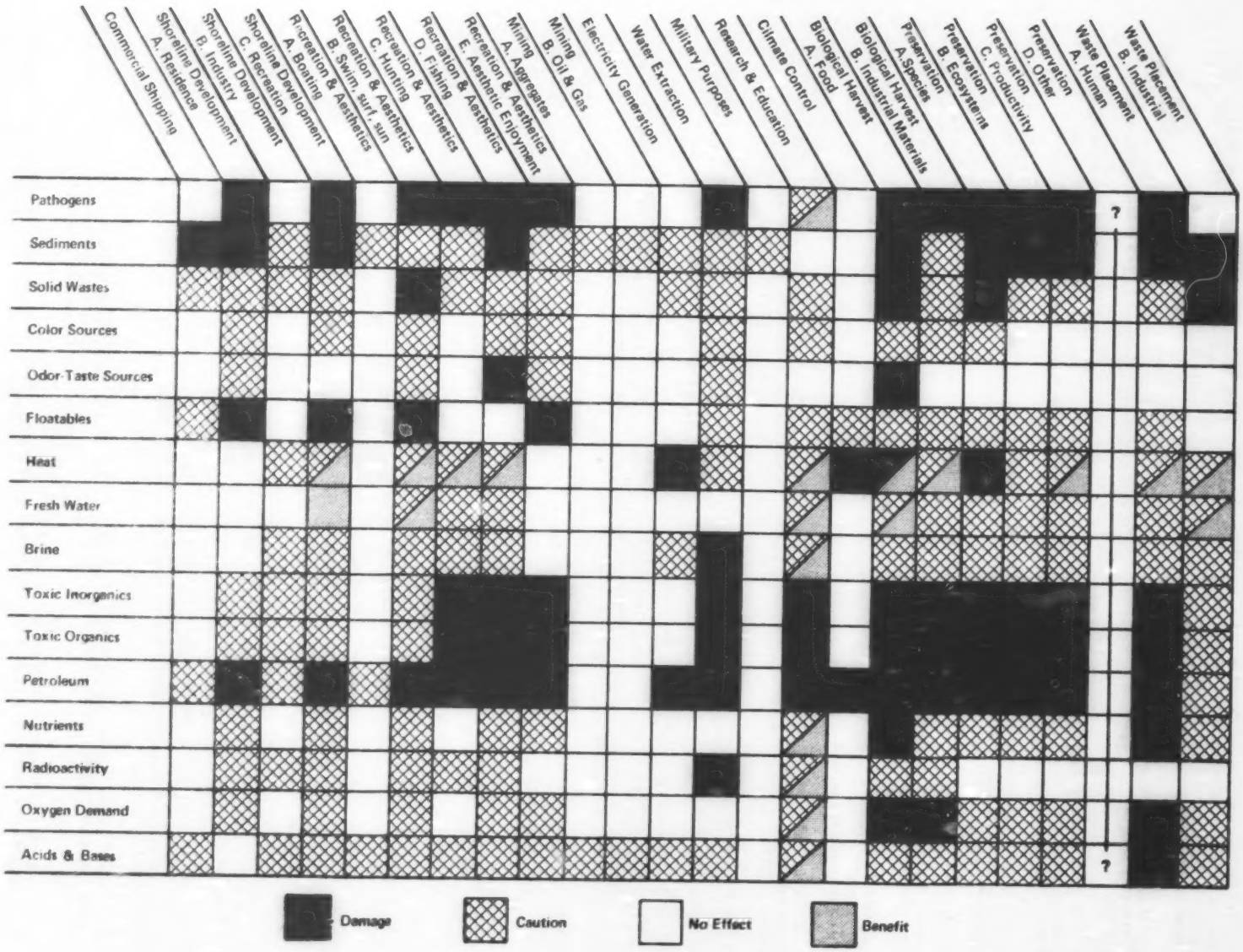

FIGURE 2.—Probable effects of pollutants on the uses of estuaries.

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APPENDIX A

Previous Lists of Uses of Estuaries and Coastal Waters (Chronological order)

Batelle, 1966. In Development Potential of U.S. Continental Shelves. ESSA, Dept. Commerce (Cited from Teeters 1968)

Mining and Petroleum
Marine Engineering
Recreation
Health and Welfare
Transportation
Food and Agriculture
Defense and Space
Research and Development
Other Industry

The original report noted 51 specific uses under these categories.

Resources for the Future, 1967. In National Interests in the Marine Environment (Cited from, and as modified by, Teeters 1968)

Economic Development
  Resource Development
  Transportation and Communication Facilities
  Recreation
  Disposal of Wastes
National Security
  Defense of U.S. Territories
  Support of U.S. Forces
Promotion of Cultural and Social Values
  Research and Development
  Preservation of Natural Beauty
  Enjoyment of the Environment

Cowel, 1968. "Coordinating Governmental Coastal Activities" (Cited from Teers 1968)

Resources
  Animal
  Non-living
  Vegetable
  Energy (tidal)
  Repository for Wastes
Enjoyment
  Recreation
  Aesthetic
Transportation
  Sea-oriented
  Land-oriented
National Defense
Land and Sea Use
  Private
  Commercial
  Industrial
  Military
  Other

Ippen, 1968. "Identification of Problems and Opportunities and Needs, Existing and Potential" (Cited from Teeters 1968)

Urbanization
Industry
Transportation
Mining
Waste Disposal
Pest Control (predominantly insects)
Defense
Agriculture
Power Production
Water Supply
Recreation
Commercial Fishing
Research and Education

The National Estuarine Pollution Study, 1969. Volume I, Part 2, pp. 30–44.

Fishing
Recreation
Transportation and National Defense
Municipal and Industrial Water Supply
Waste Disposal
Exploitation of Mineral Resources
Aquaculture
Shoreline Development

Ketchum, B. H., 1969

Swimming
Boating
Sportfishing
Commercial Fishing
Boat Yards and Marinas
Housing
Land Fill and Development
Marine Transportation
Dredging and Filling
Industry
Mining and Petroleum

National Estuary Study, 1970. Appendix F, pp. 6–7

Water Transportation
Commercial Fisheries
Extractive Industries
Water Utilization and Estuarine Discharge
Urbanization
Recreation
Research and Education

National Estuary Study, 1970. Appendix G

Commercial
Deep-draft Transportation
Boating
Mining and Minerals
Fisheries
Wildlife
Waste Disposal
Recreation
Aquaculture
Residential
Industrial
Education-Research
Water Supply
Agriculture
Defense
Power Production
Log Storage

Lill, Gordon, 1970(?). For California Advisory Committee on Marine Resources (These are apparently more accurately called activities than uses)

Policing, Control, Inspection, Regulation
Breakwaters, Dredging, Coastal Maintenance
Right of Way, Easements, Access Roads
Commercial Harbors and Terminals
Shipping
Commercial Fishing
Kelp Harvesting
Shellfish Farming
Sand and Gravel Production
Petroleum Production
Nuclear Power and Desalination Plants
Non-petroleum Offshore Platforms and Other Construction
Federal Government Reservations
Public Coastal Parks
Public Underwater Parks
Underwater Research Parks Assigned Use
Resorts
Housing and Other Real Estate Development
Swimming, Surfing, Water Skiing, Sunbathing
Surf fishing
Boat Sport Fishing
Marinas and Recreational Boating
Waste Disposal

Coastal Zone Workshop on Critical Problems of the Coastal Zone, 1972. Discussion topics

Food
Waste Disposal
Mining and Extraction
Recreation and Aesthetics
Commerce (Transportation)
Habitation (Human)
Scientific Preserve
Industrial Land Use
Power Production
Water and Chemical Extraction
Military Uses
Species Preservation

The Water's Edge: Critical Problems of the Coastal Zone, 1972. p. 13 of Summary of Results and Conclusions

Living space and Recreation
Industrial and Commercial Activities
Waste Disposal
Food Production
Natural Preserves
Special Governmental Uses

The Water's Edge: Critical Problems of the Coastal Zone, 1972. Uses discussed in various chapters.

Living Resources
  Commercial Fisheries
  Sport Fisheries
  Aquaculture
Non-renewable Resources
  Petroleum and Natural Gas
  Sand, gravel and shell
  Minerals
Recreation and Aesthetics
  Swimming
  Surfing
  Skin Diving
  Pleasure Boating
  Sport Fishing
  Tourism and Recreation
  Coastal Preserves
Urbanization and Industrial Development
  Housing
  Industrial Development
  Energy Needs
  Government Uses
Transportation and Coastline Modification
  Shipping and Commerce
Waste Disposal

Ellis, Robert N., 1973. Uses of Chesapeake Bay

Waste Disposal
Wetlands (Natural Production)
Commercial Fishing
Water Supply
Commercial Marine Transportation
Recreation
Shoreland Residential Development
Shoreland, Commercial/Industrial Development
Preservation
Mineral Resources

Clark, John, 1974. Coastal ecosystem uses

Aesthetics
Commercial Fishing
Mining
Mariculture
Transportation
Utilities
Recreation
Residential Construction
Preservation of Fish and Wildlife

EPA, 1975. Conference on Estuary Pollution Control—Uses listed for discussion

Waste Disposal
Sport Fishing
Commercial Fishing
Mining
Transportation
Electric Generation
Wildlife
Recreation

APPENDIX B

Previous Lists of Pollutants of Estuaries (Chronological Order)

The National Estuarine Pollution Study, 1969. Volume I, Part 2, pp. 52

Decomposable Organic Material
Flesh-tainting Substances
Heavy Metals
Mineral Salts
Pathogenic Organisms
Toxic Materials
Thermal Pollution
Sediment
Oil

Wastes Management Concepts for the Coastal Zone, 1970. Provides discussion on the following:

Pesticides
Sludges and Solid Wastes
Heat
Oil
Toxic Substances
Nutrients
Dissolved Organics
Oxygen Demand
Brine
Fresh Water

The Water's Edge: Critical Problems of the Coastal Zone, 1972. Considered to be of special concern:

Trace Metals
Plant Nutrients
Organic Additions
Solid Wastes
Radioactivity
Pathogens
Heat
Dredging, Filling, Marine Mining

Water Quality Criteria, 1972. Principal categories considered by the Panel on Marine Aquatic Life and Wildlife

Temperature
Inorganics (including Heavy Metals and factors affecting pH)
Oil
Toxic Organics
Oxygen Demand
Radioactive Materials
Sewage and Nutrients
Solid Wastes

Clark, John, 1974. Environmental Events

Biological Oxygen Demand
Dissolved Oxygen
Nutrients
Pathogens
Floatables
Odors and Tastes
Color
Toxicity
Dissolved Salts
Radiological
Temperature
pH Buffering
Ground Water

EPA, 1975. Conference on Estuary Pollution Control. Pollutants listed for discussion

Oil
Solid Wastes
Sediments
Nutrients
Sewage
Heat
Synthetic Organics
Metals
Chlorination
Bacteria and Viruses
Agricultural Wastes

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